PALEOCLIMATE OF ONDIRI SWAMP, KIKUYU, KENYA

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DECLARATION AND CERTIFICATION

This dissertation is a result of my original work and has not been submitted for a degree in any other university

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ABSTRACT

Ondiri Swamp is located at longitude 36°40´S and latitude 1°15´E in Kikuyu Division, Kiambu District, Central Province. Ondiri Swamp has an area of approximately 0.468Km^2, and is situated about 10 Km west from the centre of Nairobi City. It lies at 2,200m (a.s.l) and 10 m below the general topography of the area hence exhibits less hiatuses and is a major source of Nairobi River. Kikuyu town is highly populated with total density of approximately 650 people per Km^2. There is increasing pressure with the population growth rate at 2.6% per year. Ondiri swamp is situated within that part of Eastern Africa that is influenced by the monsoonal systems of Asia and the Indian Ocean with rainfall ranging from 800mm-1200mm yr^{-1} (ILRI-UNEP, 2000). The vegetative cover comprise of species of Cyperaceae, reeds (Plagmites), *Typha* (Cattails) and water grass (Vossia) which are aquatic plants. The area is underlain by the Limuru trachytes and associated pyroclastic rocks which were the final outpours of the Rift volcanic lava during the Miocene-Pleistocene times. A 50cm core was recovered at the centre of the swamp (about ten metres from the edge) during fieldwork in May 2007 to reveal the paleoclimate through use of diatoms assemblages and geochemistry of the sediment. The results from the varied lithology reveal major gaps in the depositional systems indicating time lapse in the geological record. The major diatoms at Ondiri Swamp were *Amphipleura pellucida, Navicula gawaniensis, Pinularia tropica, Eunotia tenella*, *Melosira ambigua*, *Nitzschia subrostrata*, *Surirella sp.*, *Eunotia pectinalis*, *Cyctotella iris*, *Nitzschia latens* and *Strauroneis phoenicenteron* which are mainly associated with larger and more open wetland. The younger level was dominated by *Navicula tenella, Navucula el Kab, Nitzschia linearis*, *Navicula halophila*, *Gomphonema gracile*, *Navicula. salinicola, Frustulia rhomboides Eunotia pectinalis* and *Hantzschia amphioxys* which are associated with smaller wetlands. The geochemistry of Ondiri Swamp shares similarities with the major rock types and associations with the

tectonic activities in the surrounding areas. Ondiri Swamp has undergone major changes in its paleoclimatic history probably influenced by the geological or tectonic controls given the down core variations in Lithology, changes in geochemistry and associated diatoms communities.

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Tom Odhiambo Nyaoke *my Sweet Husband*

Santana Atieno Odhiambo *my Daughter*

Raulins Nyaoke Odhiambo *my Son*

Syprose Omawa Odhiambo *last Daughter*

Henry Oswe Ogondo and Mama Florence Oswe Ogondo

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List of abbreviations and acronyms

a.s.l.	above sea level
Km	kilometer
cm	centimeter
cc	cubic centimeter
BP	radiocarbon years before present (1950)
AD	anno domino
AMS	accelerated mass spectrometer
Cal	calibrated
ca.	circa
g	grams
Mt	mount
yr.	year
ppm	parts per million
%	percent
C_3 Plants	Mountane species
C_4 Plants	Dry land species

CHAPTER ONE

INTRODUCTION

This chapter exemplifies the main subject of study and the project background; why the project was chosen and scope; the present-day environmental and climatic setting of Ondiri Swamp in East Africa in terms of the rainfall, temperatures, humidity and flora; population and communication; physiography and drainage; geology and structures; the past and present day environments of Ondiri swamp; the aim and objectives of the research; previous work done at the swamp; diatoms studies in Kenya and Eastern Africa and placement of Ondiri swamp in the paleoclimatic context compared to other proxies from Mid-to-late Holocene within Eastern Africa.

1.1 Background Information

Climatic variations in the past played a role in determining both the biotic and abiotic conditions of today, yet climate conditions and climatic variations in the recent past are still poorly understood. Paleoclimate records from the tropics are scarce compared to data available for higher latitudes, despite the central role of the low latitudes in the global climate system, especially with respect to the hydrological cycle (Broecker, 1997a; Cane, 1998; Stocker, 1998; Hoerling et al., 2001; Kerr, 2001).

Wetlands including lakes and swamps sediments are natural archives that provide long-term records of past changes in climate-catchment processes as well as changes in biological communities. The diatomaceous sediment deposit holds the archives of knowledge in paleoclimate studies and their analyses have provided a wealth of interesting and important information about paleo-environmental investigations and climate change (Owen, 2002; Owen and Renaut 2000; Barker, et al, 1990; Feibel et al., 1991). Often a core is taken from the sediments of a limnological system, and the fossils, geological and chemical signals that are preserved in the core are the clues to revealing the ecological history of the lake or swamp and the surrounding landscape. These

clues can often result in quantitative and qualitative reconstructions of important lakes or swamps chemistry and biology.

1.2 Problem Statement

A lot of Paleoclimatic data (in Kenya and Eastern Africa) have been gathered from very large lakes (Lake Victoria, Lake Turkana, Lake Naivasha, Lake Malawi, Lake Tanganyika, etc). The area covered have long-term patterns of climatic change with low resolution to paleoclimate given that they encompasses very large geographical margins hence the advent of anthropogenic changes may not been well addressed.

The Paleoclimatic studies which have been done have mostly concentrated on the recent successive lakes and lake margins, with comparatively few studies being carried out in either fluvial (e.g. Pentecost et al., 1997), wetlands (e.g. Cholnoky, 1970; Gasse, 1987) or within the main land/ancient lakes (e.g. Owen et al., 1982). In fact, most of these studies have concentrated on Pliocene and Pleistocene early hominid site but very little has been done in swamps.

Ondiri is a small swamp that would provide very high resolution data to paleoclimatic information at specific time range. The information provided is useful to policy makers because inferences of future climatic variability may not be understood unless data from the past is known.

1.3 Scope of the Research

This research aims to fill the gap in our knowledge by identifying the pattern of climatic variation in the Ondiri Swamp, Kikuyu town, Kenya (Figure 1.1). In particular, the project utilises diatom assemblages' analyses and the chemistry of the sedimentary core to reconstruct climate fluctuations and use the data to make some inferences about the greater region.

1.4 Location of Study Area

Ondiri Swamp is located at longitude 36°40´ and latitude 1°15´ in Kikuyu Division of Kiambu District approximately 10 Km west of Central Nairobi in Central Province, in Kenya which is part of Eastern Africa (Figure 1.1).

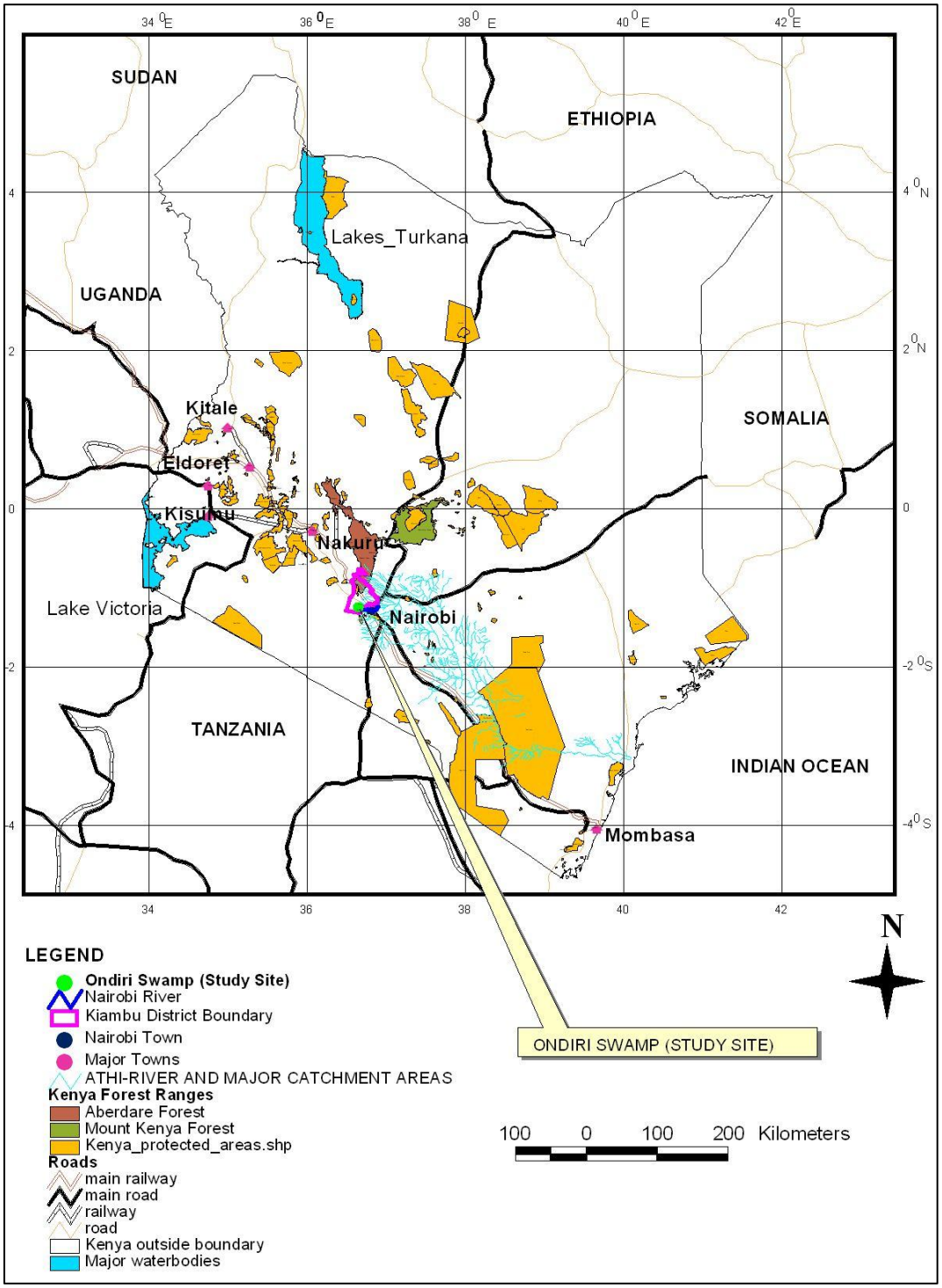


Figure 1.1 Location of Ondiri Swamp with respect to Kenya and East African region (Redrawn from Afri cover ILRI-UNEP 2000)

The area (Ondiri Swamp) is approximately 0.468Km^2 (468,000 m^2), lies approximately 2,000m (a.s.l) and 10 m below the general topography of the area (Figure 1.2). The swamp is a major source of Nairobi River that drains to main Athi River and finally to Indian Ocean.

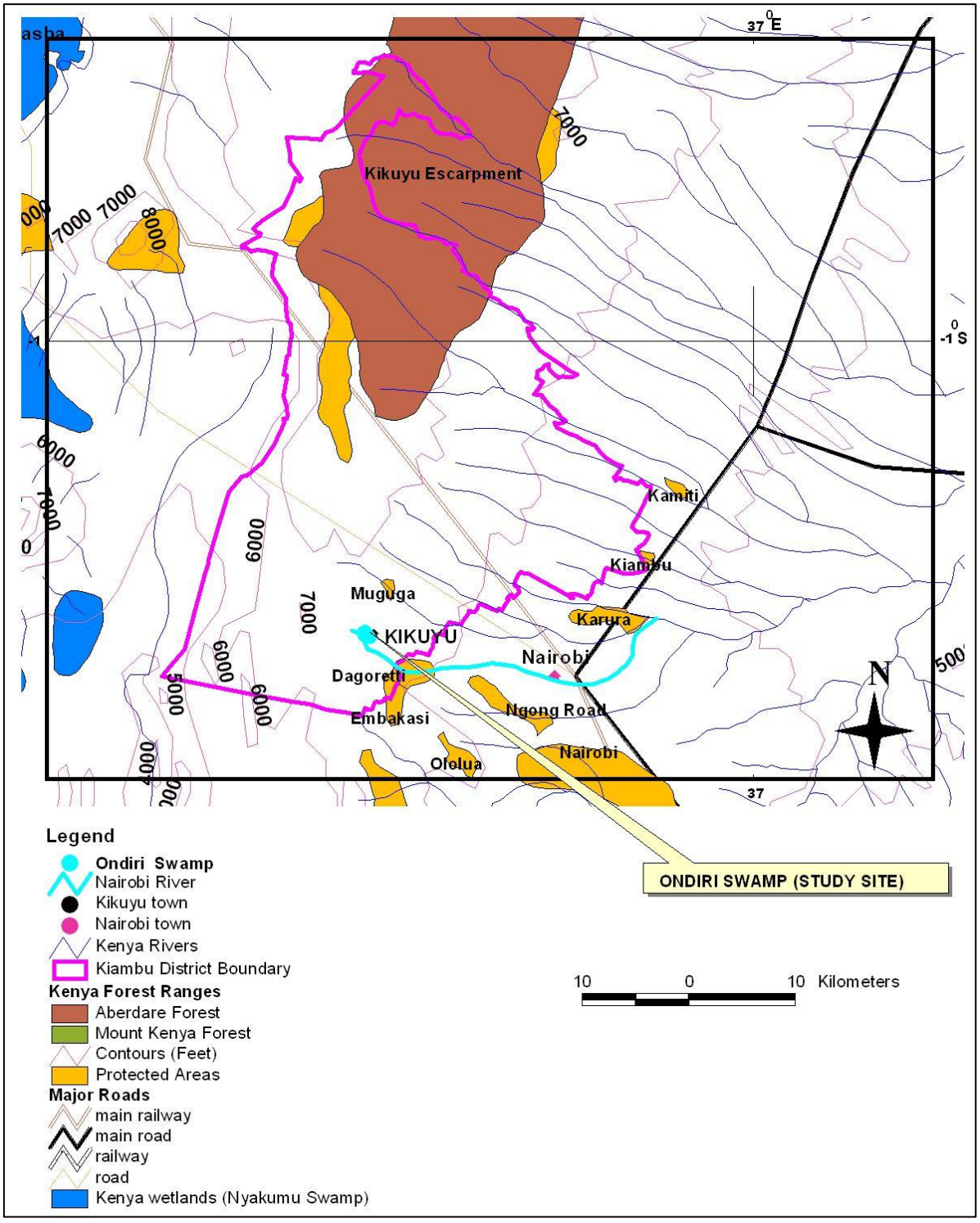


Figure1.2 Detailed topography of Ondiri Swamp (as a major source of Nairobi River) with respect to Kikuyu escarpment and other major Highlands (Redrawn from Afri cover ILRI-UNEP)

1.5 Population and Communication

Kikuyu town can be accessed through Nairobi-Nakuru highway via Dagoreti-Kikuyu road hence there exist a good communication network around Kikuyu Town (Figure 1.2). The town has good accessibility to clean water, industrial development, telephone, mail service, radios, televisions, newspapers and several magazines.

Kikuyu town and the neighbouring lands are densely populated (Figure 1.3). The total population for Kikuyu town and neighbouring locations around Ondiri swamp is 129,848 (this includes Muguga, Kikuyu, Kinoo and Karai locations) in an area of 199.11 km^2 (ILRI-UNEP, 2000), hence a total density of about 650 people per square Kilometre (ILRI-UNEP, 2000). There is increasing population pressure growth of about 2.6% per year (CBS, 1999) and the distribution of settlement throughout Kiambu district is well developed especially around the town areas (Figure 1.3).

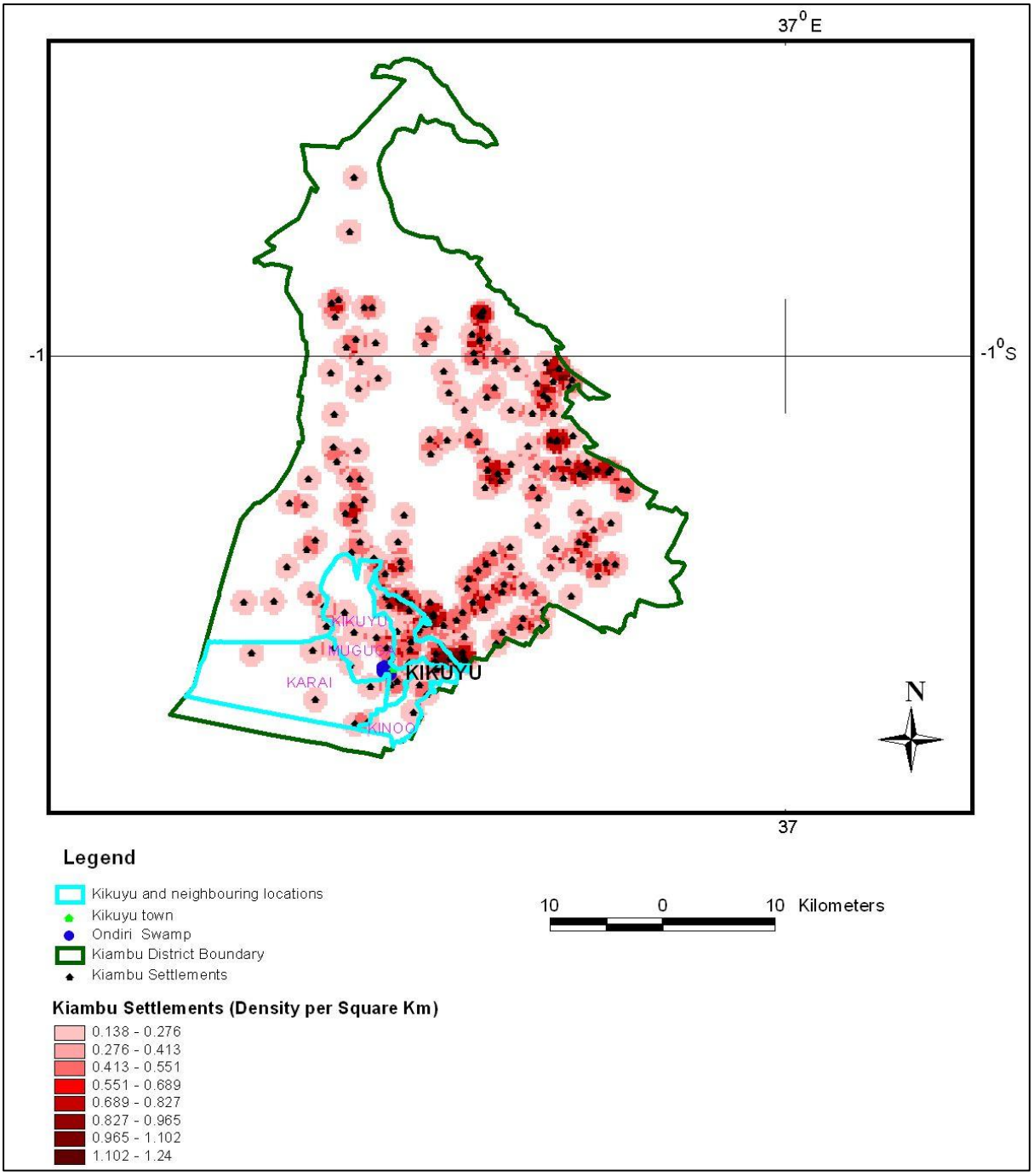


Figure 1.3: Population and settlement at Ondiri swamp and surrounding areas (Redrawn from Afri cover ILRI-UNEP 2000)

1.6 Climate

Ondiri swamp is situated within that part of Eastern Africa influenced by the monsoonal systems of Asia and the Indian Ocean. The major features of its climate are controlled by the large scale pressure systems of the western Indian

Ocean and the adjoining continents, and its day-to-day weather is related to the very considerable day-to-day variations in the details of these pressure systems (Morgan, 1967). The seasonal migration of the Intertropical Convergence Zone (ITCZ) results in northern and southern subtropical belts of monsoonal climates with summer rains and winter drought (Gasse et al, 2003), bracketing a large humid equatorial zone with two rainy seasons (Table 1.1).

Table1.1 Durations of seasons and main characteristics of weather in Nairobi (Redrawn from Morgan, 1967)

Season	**Approximate duration**	**Main Characteristics**
North-East Monsoon	December-March	North-easterly winds and sunny; warm or hot by day, with good visibility: occasionally showering periods of several days, more commonly in December and January
Rainy Season	Late March-May	Winds light and variable or light easterly, usually north –easterly at first and south-easterly later: periods of rain and showers may occur interspersed with dry periods; usually becoming cloudier towards the end of the period
South-East Monsoon	June-October	Persistent south-easterly winds; usually cloudy or overcast and cool or even cold at higher altitudes where mist or fog and drizzle are common; little rain in first of season, but increasing amounts during the latter half
Rainy Season	November	Winds light easterly, changing from south-easterly to north easterly throughout the month: usually warm, sunny and showery

East Africa experiences strong fluctuations in inter-annual and inter-decadal rainfall which have been correlated with anomalies in sea surface temperatures (SSTs) and with zonal atmospheric circulation over the tropical oceans (Griffiths, 1972; Nicholson, 1996; Nicholson et al., 1997). Rainfall fluctuations in many areas have been related to the El Nino-Southern Oscillation (ENSO) (Indeje et al., 2000), but these may be more directly a response to SSTs changes in the Indian Ocean (Beltrando, 1990; Camberlin, 1995; Birkett et al., 1999) which occur in the context of ENSO.

Humid air from the southern subtropical Atlantic Ocean, the so-called Congo Air, can penetrate far inland throughout the year according to the position of the equatorial trough and represents a major source of rain over equatorial East Africa. East Africa thus receives moisture from both the Indian and the Atlantic oceans.

1.6 a) Rainfall

Ondiri Swamp is situated close to areas that receive most rain throughout the year like the Aberdare highlands with annual precipitation of approximately of over 2,000 mm yr^{-1} (Afri cover ILRI-UNEP, 2000). The rainfall gradient from the surrounding elevated highlands is higher ranging up to 2,000-2,400 mm yr^{-1} but Ondiri Swamp has rainfall ranging from 800mm-1200 mm yr^{-1} (Figure 1.4). Rains fall mainly in two seasons, 80% of the total annual rainfall account from March to May (the long rains) and in November (the short rains).

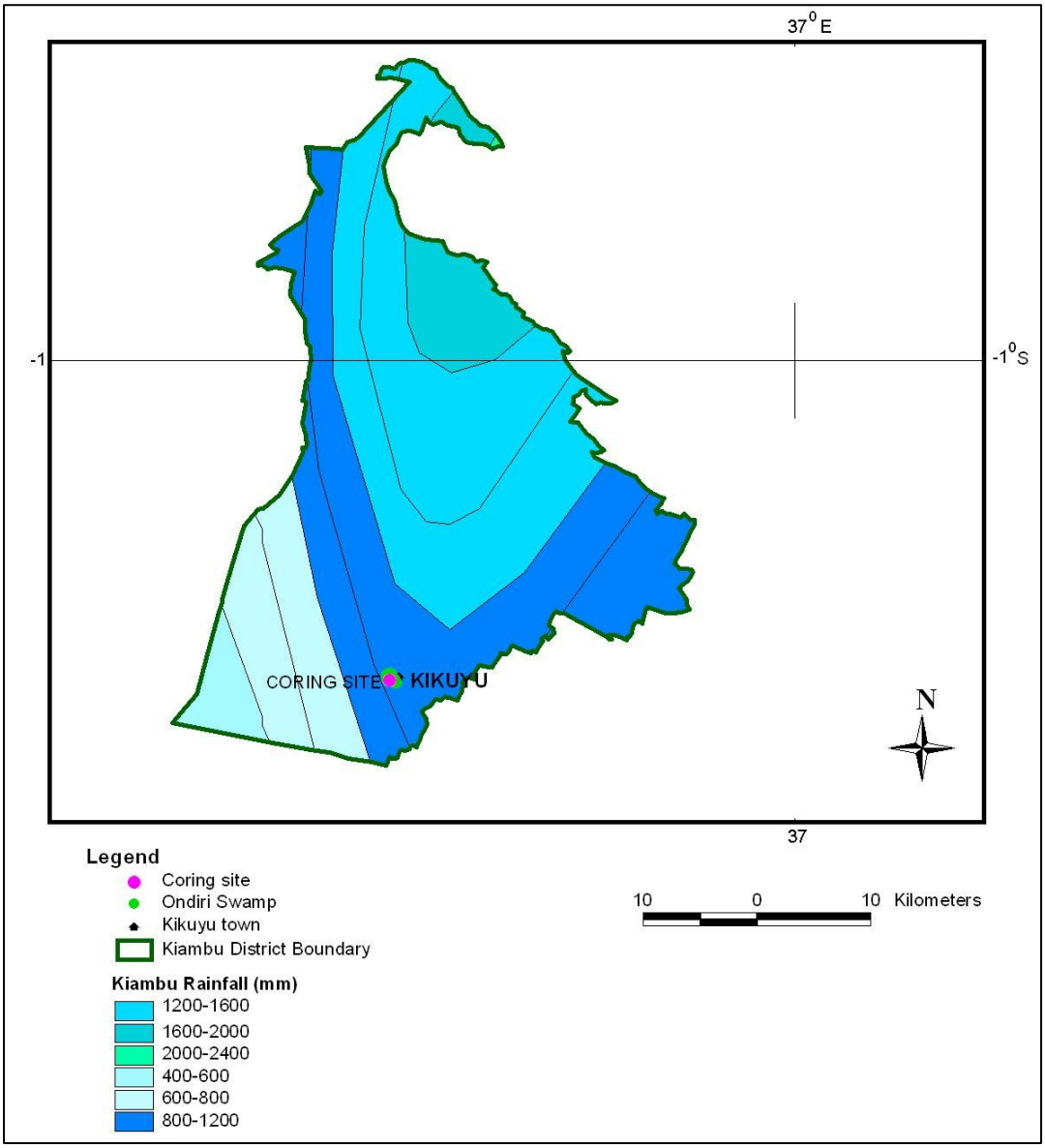


Figure 1.4: Rainfall distribution of Ondiri Swamp and surrounding areas (Redrawn from Afri cover ILRI-UNEP 2000)

1.6 b) Temperature and humidity

The annual mean temperature ranges from 15-18^{0}C, with a minimum of 8-11^{0}C decreasing in value with increasing altitude (Afri cover ILRI-UNEP 2000). The area is generally sub-humid to semi-humid (Figure 1.5). In the morning it frequently reaches saturation and may fall to 10% in the middle of the day on clear sunny days in February or March. There is bright sunshine most parts of the day the afternoon being highest.

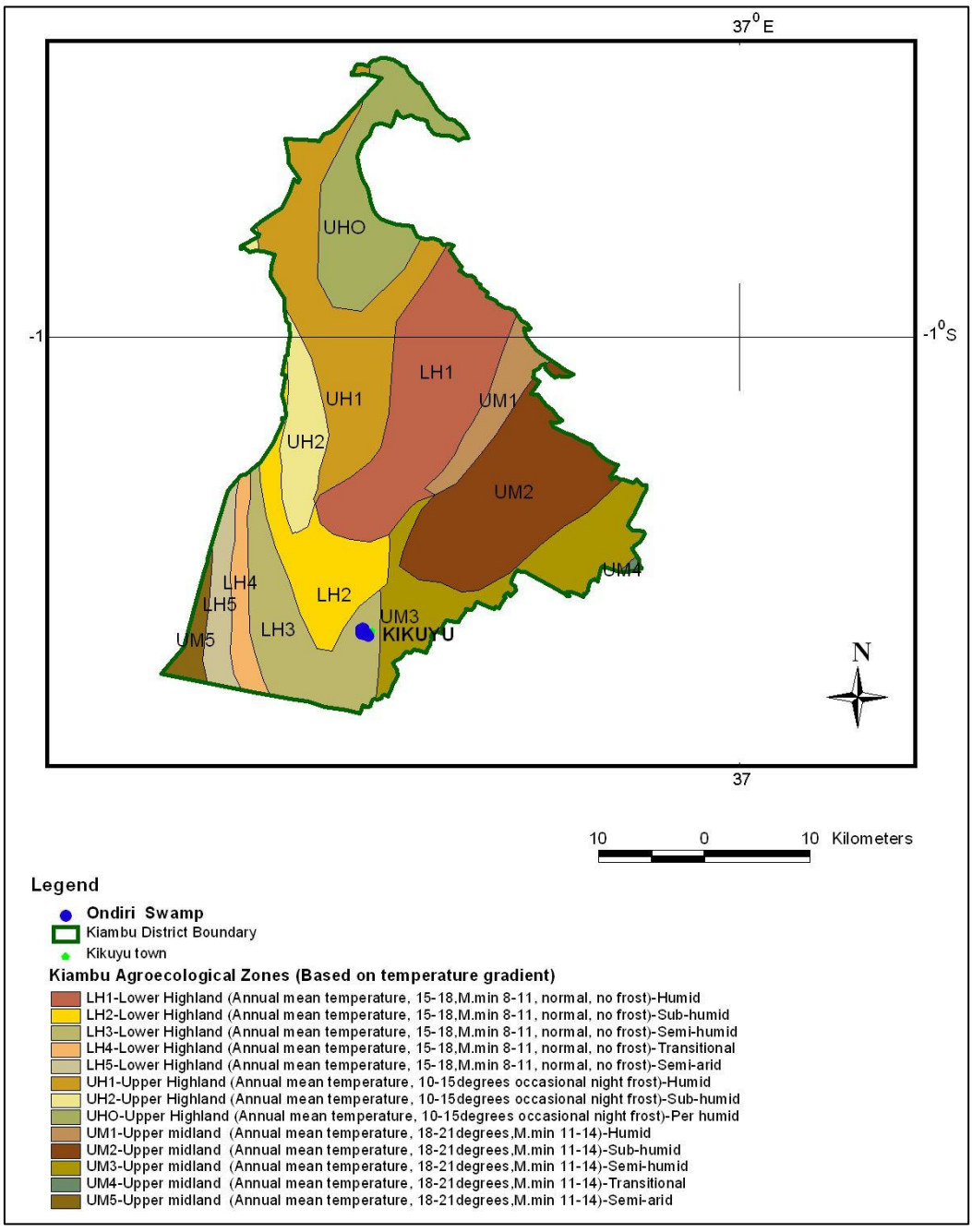

37^{0}E
-1
-1^{0}S
37
UHO
LH1
UH1
UM1
UH2
UM2
UM4
LH4
LH5
LH2
LH3
UM3
KIKUYU
UM5
N
10 0 10 Kilometers
Legend
Ondiri Swamp
Kiambu District Boundary
Kikuyu town
Kiambu Agroecological Zones (Based on temperature gradient)
LH1-Lower Highland (Annual mean temperature, 15-18,M.min 8-11, normal, no frost)-Humid
LH2-Lower Highland (Annual mean temperature, 15-18,M.min 8-11, normal, no frost)-Sub-humid
LH3-Lower Highland (Annual mean temperature, 15-18,M.min 8-11, normal, no frost)-Semi-humid
LH4-Lower Highland (Annual mean temperature, 15-18,M.min 8-11, normal, no frost)-Transitional
LH5-Lower Highland (Annual mean temperature, 15-18,M.min 8-11, normal, no frost)-Semi-arid
UH1-Upper Highland (Annual mean temperature, 10-15degrees occasional night frost)-Humid
UH2-Upper Highland (Annual mean temperature, 10-15degrees occasional night frost)-Sub-humid
UHO-Upper Highland (Annual mean temperature, 10-15degrees occasional night frost)-Per humid
UM1-Upper midland (Annual mean temperature, 18-21degrees,M.min 11-14)-Humid
UM2-Upper midland (Annual mean temperature, 18-21degrees,M.min 11-14)-Sub-humid
UM3-Upper midland (Annual mean temperature, 18-21degrees,M.min 11-14)-Semi-humid
UM4-Upper midland (Annual mean temperature, 18-21degrees,M.min 11-14)-Transitional
UM5-Upper midland (Annual mean temperature, 18-21degrees,M.min 11-14)-Semi-arid

Figure 1.5: temperatures and humidity of Ondiri swamp and surrounding areas (Redrawn from Afri cover ILRI-UNEP 2000)

1.7 Vegetation

Ondiri Swamp has numerous species of Cyperaceae, reeds (Plagmites), *Typha* (Cattails) and water grass (Vossia) which are aquatic plants which grow continuously and produce large amounts of organic debris (Plate 1.1) that decompose and accumulate to form a thick mat (50cm thick) on top of the water (Kinyanjui, 2003).

flooded land because of the permanent swamp (Figure 1.6), with other neighbouring land having open trees (65-40%) cover of very little of the indigenous types of the vegetation remaining after heavy cultivation by the inhabitants of the area including the Mountane forest taxa of *Podocarpus milanjianus* and *Ocetea usumbarensis*. A dry semi-deciduous forest (Figure 1.6) was noted dominated by *Croton megalocarpus* and *Brachylaena hutchinsii* with *Calodedrum capense*, *Teclea spp.*, *Strychnos henningsii* and *Diospyros abyssinica, Cupressus sp., Graviliea robusta,* and major savannah species in the scrub savannah lands including *Acacia* species and the grasslands (Williams, 1967).

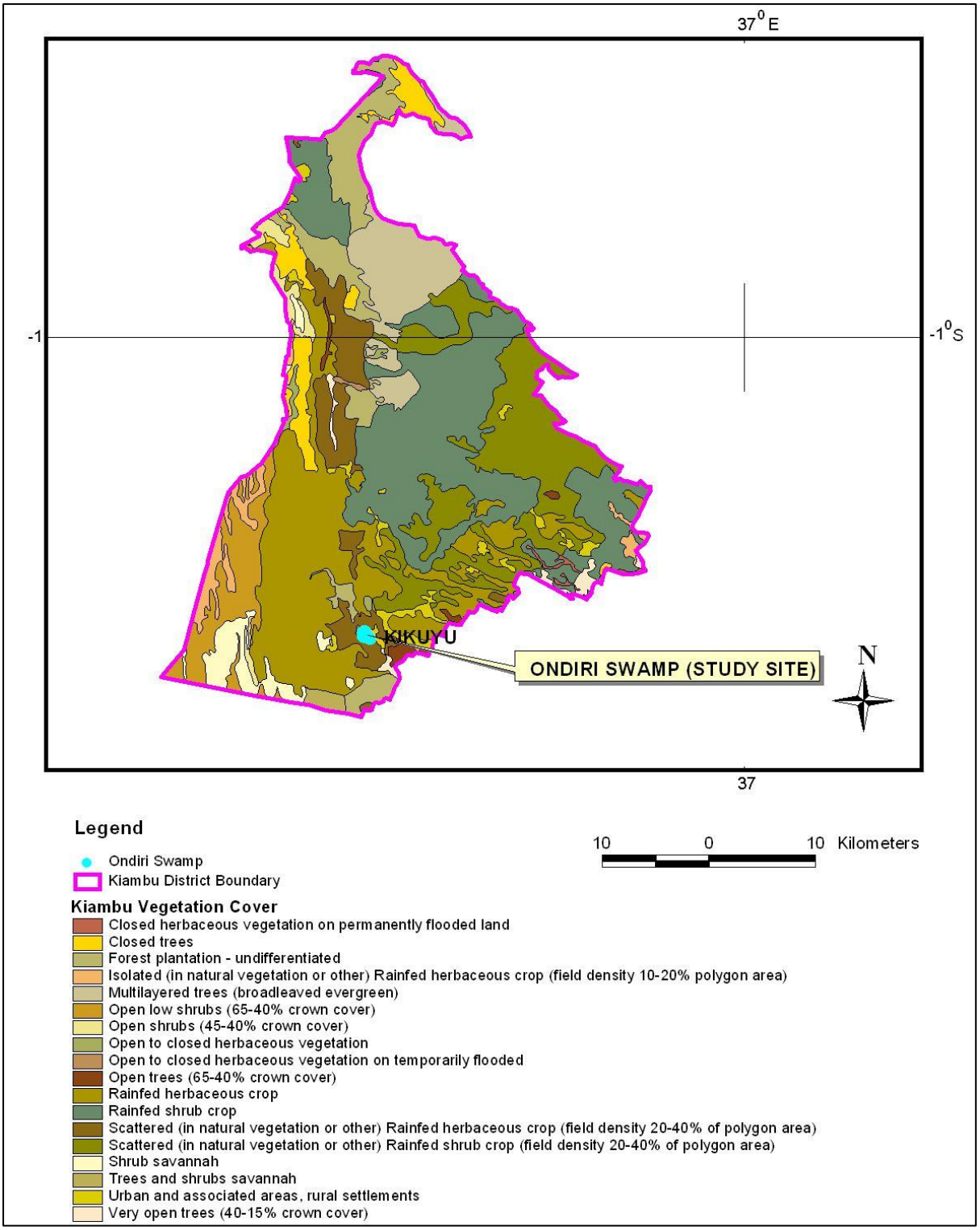

37° E
-1
-1° S
KIKUYU
ONDIRI SWAMP (STUDY SITE)
N
37
Legend
10 0 10 Kilometers
Ondiri Swamp
Kiambu District Boundary
Kiambu Vegetation Cover
Closed herbaceous vegetation on permanently flooded land
Closed trees
Forest plantation - undifferentiated
Isolated (in natural vegetation or other) Rainfed herbaceous crop (field density 10-20% polygon area)
Multilayered trees (broadleaved evergreen)
Open low shrubs (65-40% crown cover)
Open shrubs (45-40% crown cover)
Open to closed herbaceous vegetation
Open to closed herbaceous vegetation on temporarily flooded
Open trees (65-40% crown cover)
Rainfed herbaceous crop
Rainfed shrub crop
Scattered (in natural vegetation or other) Rainfed herbaceous crop (field density 20-40% of polygon area)
Scattered (in natural vegetation or other) Rainfed shrub crop (field density 20-40% of polygon area)
Shrub savannah
Trees and shrubs savannah
Urban and associated areas, rural settlements
Very open trees (40-15% crown cover)

Figure 1.6: The distribution of vegetative cover around Ondiri Swamp (Redrawn from Afri cover ILRI-UNEP 2000)

1.8 a) Physiography

The Physiography of the areas around the Ondiri Swamp comprise plateau sloping up to its edge and its step-faulted flank. The inclined plateau of the ramp rises in elevation at an average gradient of between 1% to 3% in distance varying from the Athi-river between 1,560-1,630 metres a.s.l in the east to the watershed line along the Ngong hills and Kikuyu escarpment which has maximum and minimum of 2,690 and 2166 metres a.s.l (Figure 1.7 a, b). Regional slopes of the volcanic rocks flow towards the east and the western part of the area is occupied by the eastern shoulder of the Rift valley where prominent scarps and fault blocks give a characteristic physiographic expression.

The region (Nairobi area) is divided into four prominent physiographic units thus:

i) The lava plains comprising the Athi plains (1,829m) and Kapiti Plains (1,493m)
ii) Kikuyu highlands, mainly the Kikuyu escarpments
iii) The rift flank of about 2,438m high
iv) Ngong hills dominate the Nairobi landscape with highest point at OlEsayeiti area about (2,134m) (Saggerson, 1991).

The topography has two marked features:

- It is on the division of Athi-plains and the foot of the Aberdare mountains,
- The deep valleys cut by the Nairobi river and Ngong streams (Figure 1.7 a, b)

Figure 1.7a): The Physiographic features on the area location and the coring sites of Ondiri Swamp, Kikuyu (Landsat Images 1980) Google Earth.

Figure 1.7b): The location of Ondiri Swamp, Kikuyu and major roads (Landsat Images 1980) Google Earth.

1.8 b) Drainage

This comprises the Kikuyu scarp which starts with a general flexure in the Magadi region gradually raises northwards to a maximum elevation in the Aberdare Mountains north of the present area (Saggerson, 1991). The underlying lava in the down thrown blocks or strips is responsible for the local perched water tables and hence development of internal drainage and swamps or lakes with sediment accumulation. Ondiri Swamp is a major source of Nairobi River and joins other minor streams from the Kikuyu escarpment (Figure 1.2) to drain to the main Athi-river which is one of the two major Kenyan rivers that drains to the Indian Ocean.

1.9 Geological setting

There are two main general geological formations within the Kiambu District thus;

i) Tertiary volcanics from the Rift Valley tectonics which erupted form two central volcanoes, Ngong and Ol Esayeiti consisting of the major phonolite, trachytes, rhyolites and tuffs (Obsidians)

ii) Younger reworked Quaternary rocks overlay tertiary rocks and in which the study area falls with alluvial, loess and lacustrine deposits (Figure 1.8)

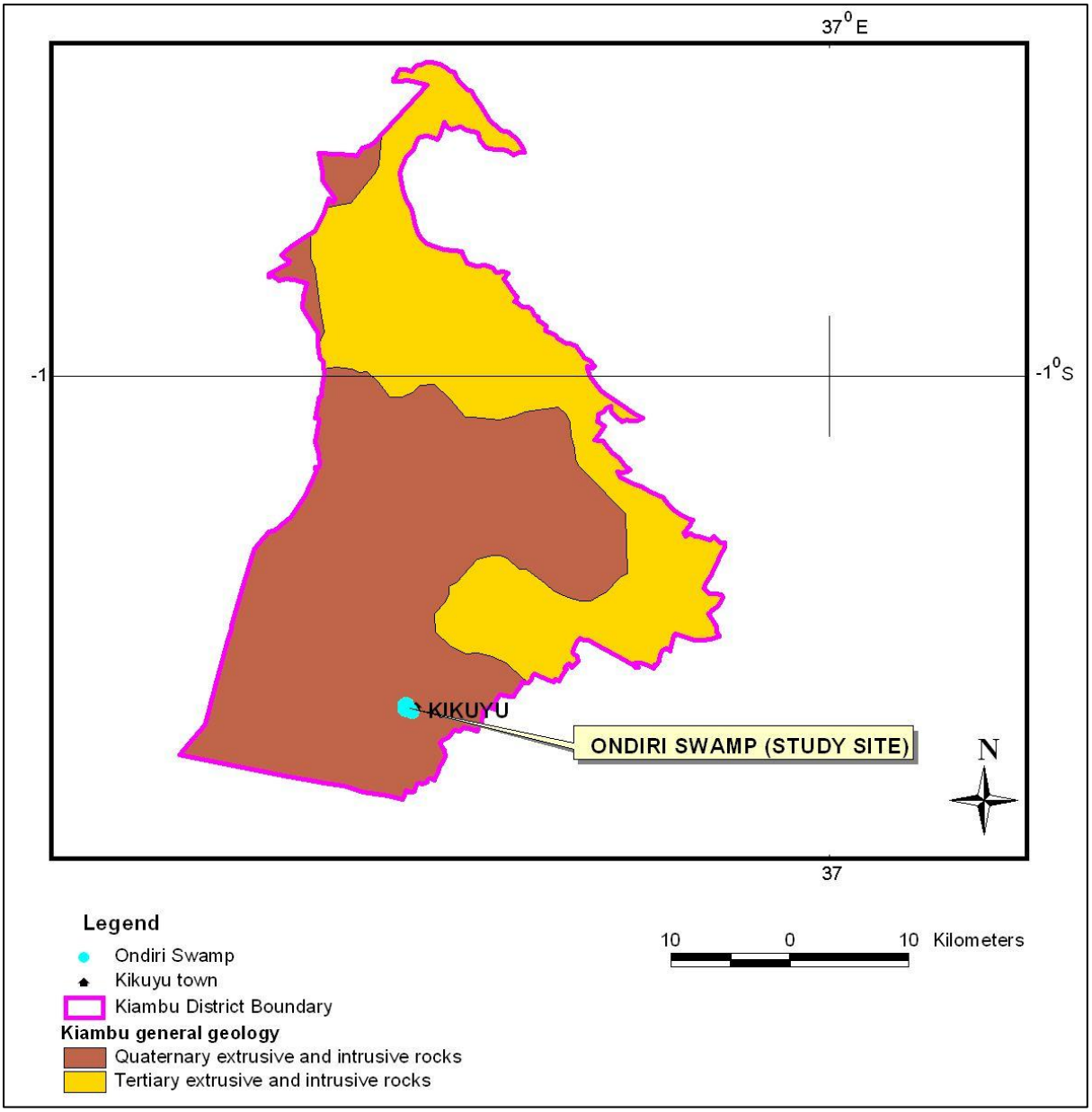


Figure 1.8: Geological setting Ondiri and surrounding area (Redrawn from Afri cover ILRI-UNEP 2000)

1.9 a) Rock distribution at Ondiri Swamp

The rocks mainly found at Ondiri Swamp are the Limuru trachyte (Plate 1.2 A and B) and associated pyroclastic rocks which were the final outpours of the Rift volcanic lava. The trachyte were derived by eruptions along fault zones connected with the rift faulting rather than central volcanoes as suggested by

Saggerson (1991). The trachyte is soft, but fissile and highly porphyritic with abundant feldspars, anorthoclase phenocrysts in a matrix of untwined orthoclase, kataphorite, aegirine-augite and rare cossyrite Saggerson (1991) dating 1.72-1.55±0.009 Ma (Baker et al. 1971).

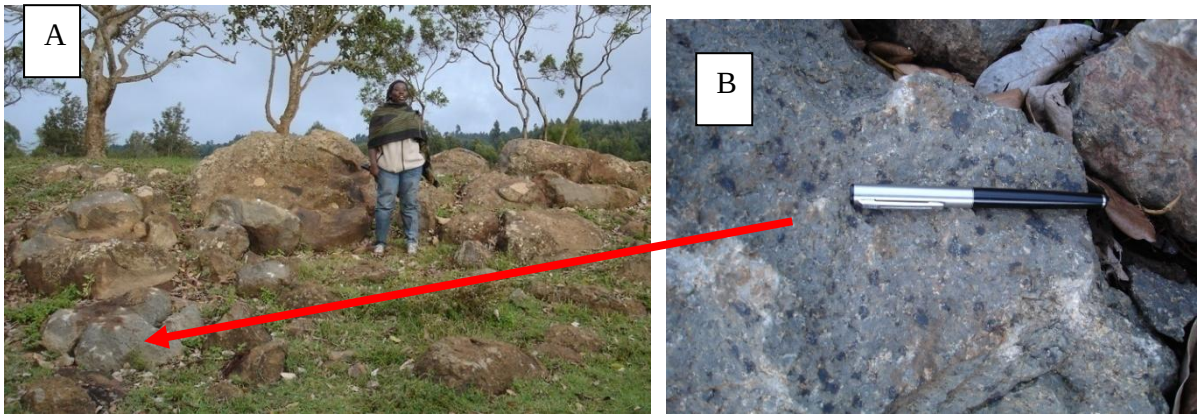


Plate 1.2: The main rock type at Ondiri swamp -Limuru trachyte (A, B)

1.9 b) Structures

The main faults in the region form part of a complex North –South fracture pattern associated with the eastern Rift valley. Two main tongues of the lava extend in an easterly direction forming prominent ridges, north of Kiambu in Nairobi (Saggerson, 1991).

The major recumbent folds with NE-SW axial trends and a number of minor cross-structures trending slightly west of north exist. The successive lava flows have a gentle eastern dip, consequent upon the slope of the ground over which it flowed.

The fault zones (Figure 1.9) are numerous within the area and its horizons with prominent scarps and ridges (Saggerson, 1991) marked by a series of impressive sub-parallel scarps between Limuru, and the Ngong hills.

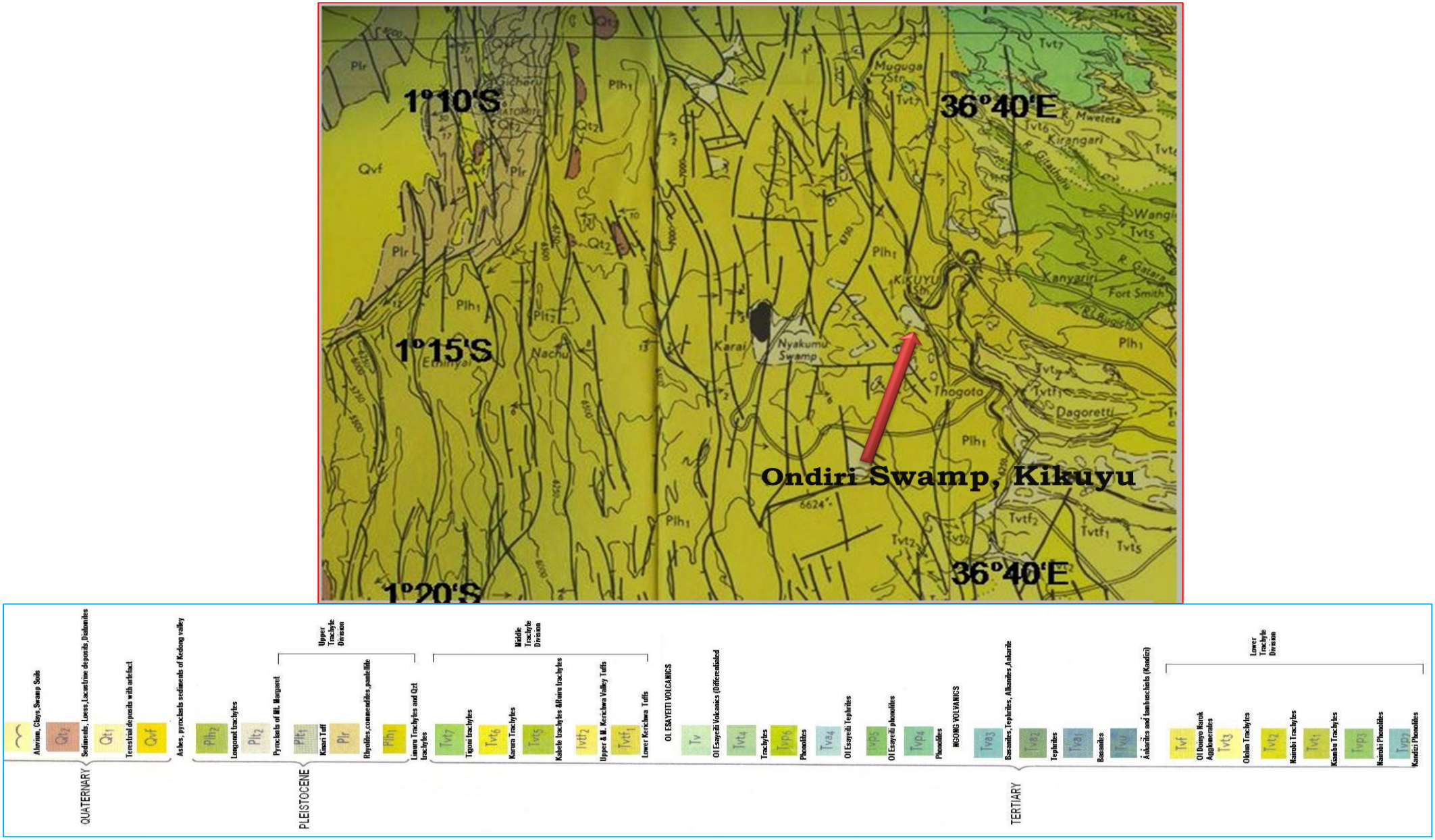


Figure 1.9: Geological setting and structures of Ondiri Swamp and surrounding areas after Saggerson (1991)

1.9 c) Soils

The Athi Plains phonolites and the Limuru trachytes have weathered through leaching and laterization into two-to-three metre deep (with secondary kunkar) formation at the junction with the parent rock (Saggerson, 1991). The soils are well drained extremely dark to reddish brown clay (Kaolinites) with organic matter at the top (Figure 1.10). The soils are easily detected by the vegetation types within the surrounding areas (Morgan, 1967).

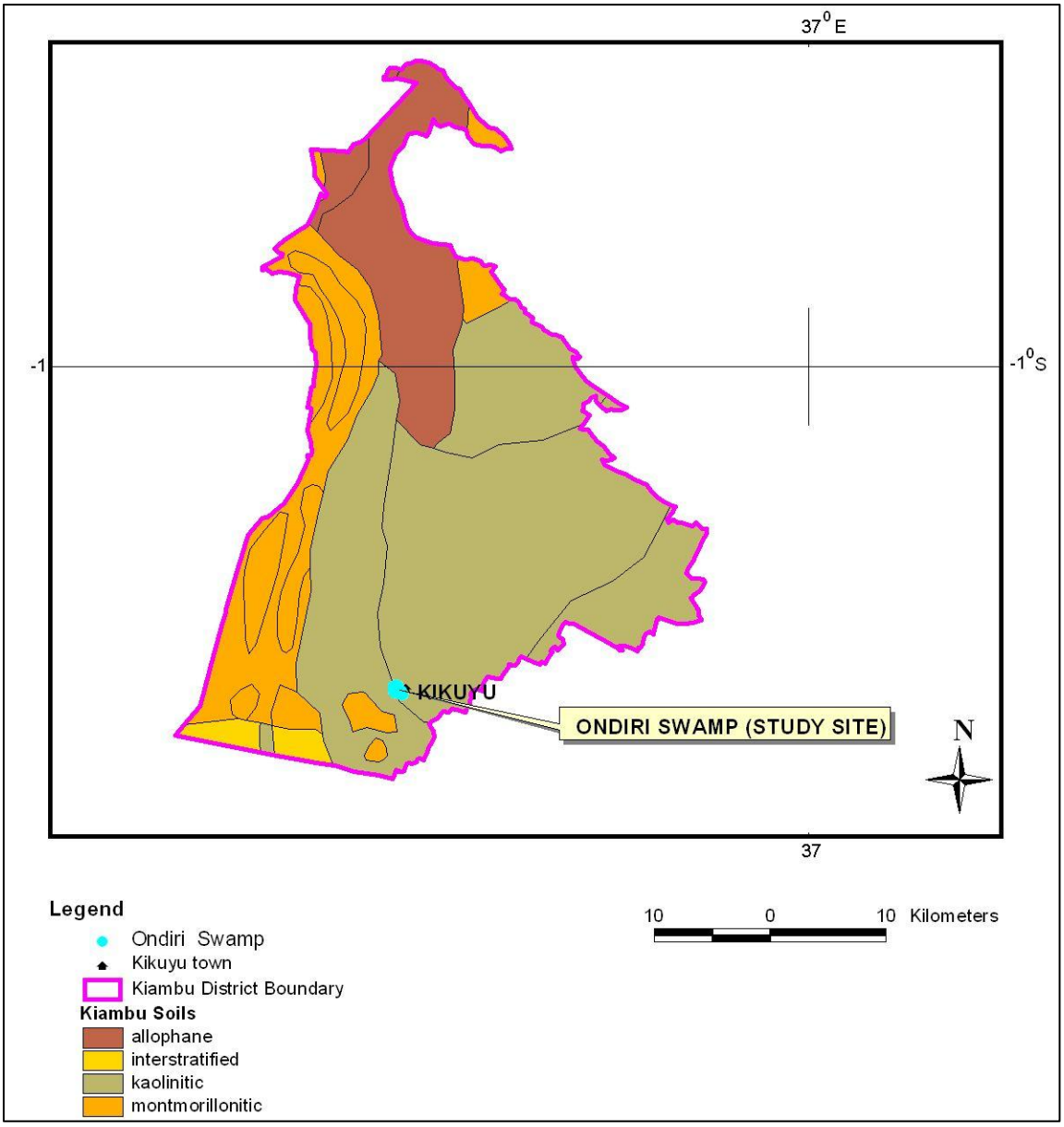
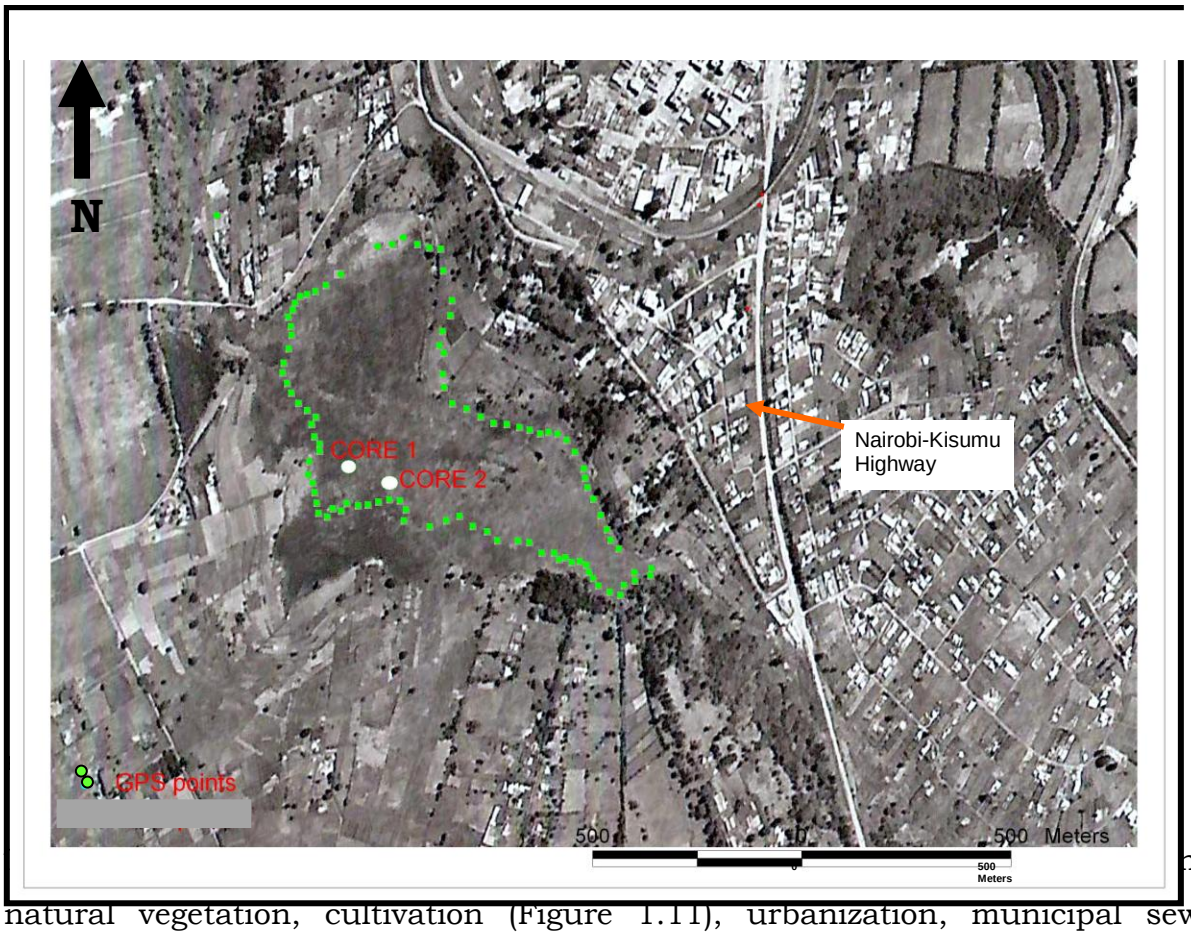


Figure 1.10: Major soil types at Ondiri Swamp and major areas (Redrawn from Afri cover ILRI-UNEP 2000)

1.10 Present day swamp and its land use

There has been a drastic vegetational change within the Ondiri Swamp and surrounding area as observed through the demonstrated short period between 1998 to present aerial image (Plate 1.3).



ng of natural vegetation, cultivation (Figure 1.11), urbanization, municipal sewage disposal, abstraction of water, use of agrochemicals and increase in industrial activity (Gichuki, 1998, Olago, 2003).

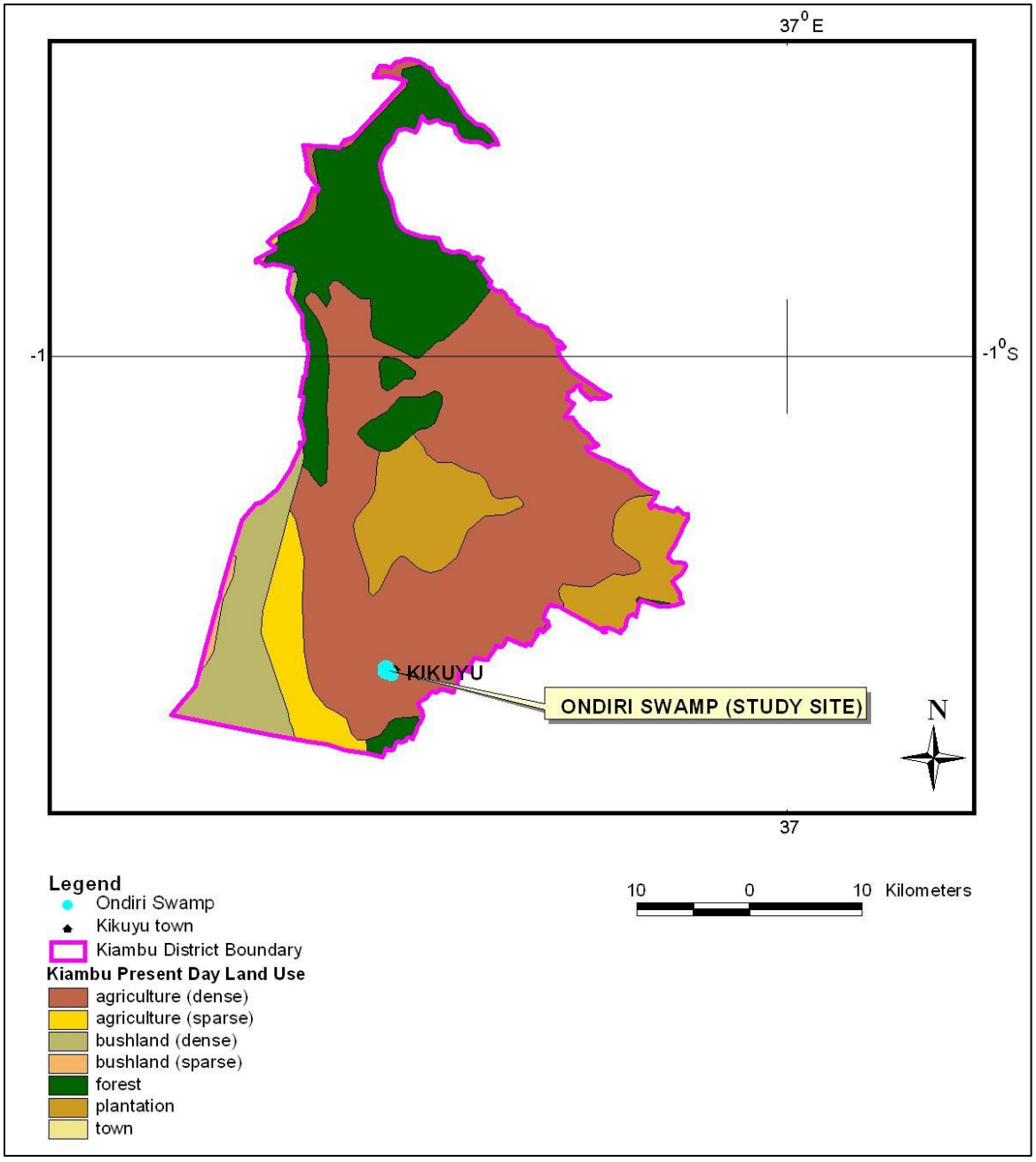


Figure 1.11: Land use of Ondiri Swamp and Kiambu District (Redrawn from Afri cover ILRI-UNEP 2000)

1.11 Ondiri Swamp sediments

All the formations are covered by deep soils (loess and lacustrine deposits) and gravel of quaternary age, and contain diatomaceous bed which reflects major

changes in climatic conditions. Olago and Opiyo, (2000) suggested that the sediments may be derived from the local geological succession (trachytes) as the major source of swamp sediments.

Saggerson (1991) suggested that a number of prominent depressions, the so called "swamp pits" by Gregory (1921) occur within the Rift faults zone of west Nairobi which vary in size from a few metres (like Ondiri Swamp) to the largest Nyakumu Swamp (Figure 1.9) depression have been thought to be due to volcanic vent deflation. Further detailed mapping shows that the depressions are merely down faulted lava blocks adjacent to the N-S trending faults and fractures and their topographic expressions have been modified by erosion of the sediments. The underlying lava in the down throw blocks or strips are responsible for local perched water tables and hence the development of internal drainage and swamps or lakes in which the sediments have accumulated (Saggerson, 1991).

Ondiri Swamp, like many other swamps in the area derive its water from underground seepages, that may be the reason why it retains water for long even during periods of droughts indicating that there is little infiltration loss.

1.12 Study objectives

The main objective of this project is to reconstruct paleoclimatic and paleo-environmental changes of the Ondiri swamp, Nairobi-Kenya using lithological, diatoms and geo-chemical analyses.

The specific objectives are to:

1. To determine the temporal changes of Ondiri swamp's sediment through chronological stratigraphic analysis of the species of diatoms.

2. To determine chronologically changes in the chemical content of Ondiri Swamp sediments.

1.13 Rationale and justification of the study

This choice of the study area was made because the swamp (as a wetland) is on a highland about 2,000 m (a.s.l) approximately 10m below the general topography of the area hence exhibits less hiatuses by the local or regional assemblages/species.

Ondiri swamp is a natural archive that can provide a long-term record of past changes in climate-catchment processes as well as changes in biological communities. The swamp derives its waters from the rift through springs; hence the project would establish the paleo-environment that existed before, and any effect of harmful anthropogenic influences, which should be ameliorated. This project aims at using the example of Ondiri swamp for the reconstruction of the Quaternary environment of the Nairobi Area and central Kenya since this has not been keenly done.

Paleoclimatic proxies are developed by using biological (pollen, diatom, phytolith, organic geochemistry), geochemical (stable isotopes, major and trace elements, radiocarbon and ^{210}Pb dating) and physical (sedimentology, rock magnetism, spectro-colourimetry) data as measured on present-day and past

soils and sediments. The combination of these climatic, environmental, land use and human activity proxy will improve the understanding of; sedimentary proxies of human impact (fire, deforestation, land-use); synchronism/a synchronism of climate and socio-economic changes such as land use, appearance, blooming and disappearance of civilizations, historical famines, human migrations, and cultural data (settlement, cattle domestication, agriculture, metallurgy, arts), adaptative strategies of human populations to environmental change. (Williamson, et al 2003)

1.13.1 The Diatoms

Diatom silica frustules (Figure 1.11) are a form of biogenic opal that is being increasingly used in paleoclimate studies (Leng, et al., 2006). Often a core is taken from the sediments of a limnological system, the fossils and geo-chemical signals that are preserved in the core are the clues to revealing the ecological history of the lake or swamp and the surrounding landscape. These clues can often result in quantitative and qualitative reconstructions of important lakes or swamps geo-chemistry and biology.

The methods used have provided good evidence for climate patterns and climatic variation of the swamp. A large repository of diatom specimens and records used and published by various authors is available and represents an as yet unutilized wealth of ecological and taxonomic information. The data has been used in conjunction with these similar data from other localities like Olorgessaillie, Kariandusi and Challa paleo-lakes to paint a more complete picture of climatic variations in the recent past, which is useful for understanding factors affecting the evolution of the world as it is today.

1.13.2 Utility of Diatoms Studies in paleoclimatic reconstruction

Diatoms are unicellular photosynthetic algae (2–200 μm) that secret a shell, or frustule, composed of opalline or biogenic silica ($SiO_2.H_2O$) (Round et al., 1990). The frustules have distinct patterns which enable identification to the species

level (See Figure 1.2). They are found in all aquatic environments, within the photic zone. Fossil diatoms are recovered from most fine grained sediment. Diatoms are affected in their distribution by climatic factors and by the trophic status of the water-body in which they exist; hence, valuable environmental information can be gleaned from studying them.

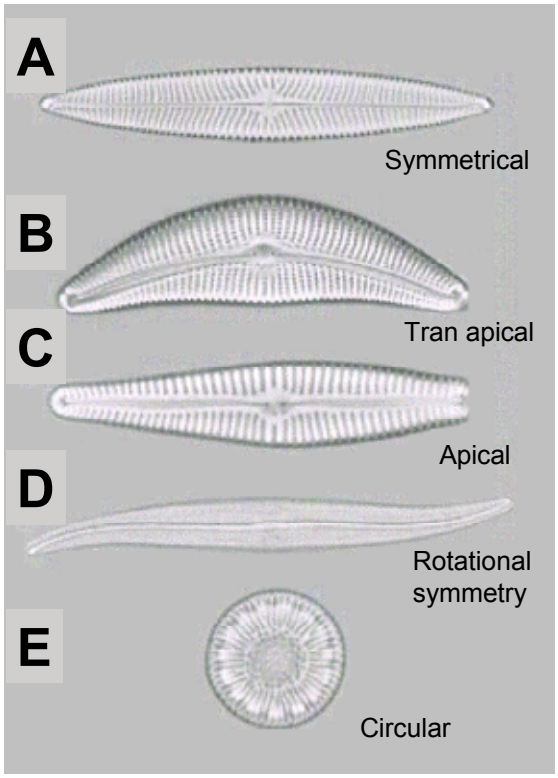


Figure 1.12: Examples of various shapes of diatoms species - Pictures not drawn to scale (Redrawn from Steve Juggins (2007); website "Taxon Information"

Additionally, recent findings show that diatoms are 'sub-cosmopolitan', that is, they occur anywhere where particular environmental conditions are fulfilled (Kelly, 1998). This concept suggests that geographical location is not the determining factor in the distribution of diatom species and the composition of communities but rather the specific environmental variables prevailing at a particular site (Gold et al., 2002). As such use of diatoms in the evaluation, and reconstruction of environmental conditions in the past and present for assessment of environmental change, is well documented (Harding, et al., 2004;

Patrick, 1973; Van Dam, 1974; Chessman, 1986; Whitmore, 1989; Dixit et al., 1992).

Some of the factors that make diatoms such an effective diagnostic tool in reconstructing past and present environments are (De la Rey et al., 2004; Schoeman and Haworth, 1986; and Harding et al., 2004):

i. They collectively show a broad range of tolerance along a gradient of aquatic productivity, with individual species having specific water chemistry requirements
ii. They have one of the shortest generation times of all biological indicators (Approximately 2 weeks). They reproduce and respond rapidly to environmental change and provide early measures of both pollution impacts and habitat restoration
iii. They are sensitive to change in nutrient concentrations, supply rates and silica/phosphate ratios. Each taxon has a specific optimum and tolerance for nutrients such as phosphate and nitrogen, and this is usually quantifiable.
iv. Their assemblages are typically species-rich – augmenting the information gained from a diversity of ecological tolerances. Moreover, the large number of taxa provides redundancies of information and important internal checks in datasets, increasing the confidence of environmental inferences
v. They respond rapidly to eutrophication. Because diatoms are primarily photoautotrophic organisms, their growth response is directly affected by changes in prevailing nutrient concentrations and light availability
vi. The rapid immigration rates and the lack of physical dispersal barriers ensure that there is little lag-time between perturbation and response
vii. Diatom frustules have a lasting permanence in sediments, such that sediment cores provide details of changes in the quality of the overlying water for as far back as one is able to search. This attribute alone has significant and far-reaching relevance for the determination of reference

conditions, not only climatic but also the condition of the system prior to intrusion from anthropogenic development

viii. The taxonomy of diatoms is comprehensively documented. Species identifications are largely based on frustules morphology – an attribute readily identifiable with modern light microscopy and image analysis techniques, and are not dependent on electron microscopic techniques as is commonly misconceived

ix. They are easy to collect, prepare for observation, and store (you only need small sample volumes, with no desiccation risk) for reference purposes

x. There is a considerable amount of tried and tested ecologically associative information already available, both nationally and world-wide

xi. Interpretive software packages like TILIA are easily available for usage

From the above therefore, it is clear that details provided by diatom assemblages supports paleoecological, paleoclimatological investigations and historical reconstruction. Furthermore through simple methods of retrieving living material from introduced artificial substrates, evaluations of the impacts arising from a variety of anthropogenic activities can be achieved. Such activities may include environmental policy and management strategies. Diatom records provide an insight into water quality conditions prevailing tens of thousands years ago prior to the development of many of the rivers, streams and wetlands. Thus diatoms offer insight into the geomorphology, hydrology, and paleoclimate in the past.

1.14 Previous work

1.14.1 Previous work in Ondiri Swamp

Ondiri Swamp, with its suitable location in a highland, has been a study site for several authors for various types of research which has unfolded its history.

Kinyanjui (2003) recovered a core and investigated the palynology and heavy metals in the sediments and water of the swamp. The pollen analysis done within the recovered core sediments provided a record indicating the past vegetation within the catchment of the swamp.

Olago (2003) investigated the interaction between urban agriculture and the fluvial systems in basins of Nairobi Rivers. The analyses of the water quality from the beginning of the twentieth century had clean waters and were later altered by anthropogenic activities e.g. population increase, urbanisation, etc. from 1960s and increased from 1970s through to the 1990s.

Ndiritu (2001) used epilithic diatom communities on both natural and artificial substrates to detect the pollution within the water catchments. In the analysis temperature, altitude and pH interacted significantly with dominant diatom species on natural substrates, which included *Gomphonema parvulum*, *Nitzschia palea* and *Navicula subminuscula*. The results indicate that abundant diatom species can be used to describe major types of aquatic environmental gradients and can serve as good indicators of ecological conditions in tropical streams and rivers.

Gichuki (1998) and Ngweno (1999) worked on the wetland to determine if it has any indigenous fauna or flora of economic value because Ondiri Swamp breads one of the major bird areas in Kenya.

Saggerson (1991) mapped the area gave a detailed geological work of the Nairobi region and analysed the successive geological units and classified the rocks around Ondiri swamp as Limuru Trachyte which Gregory (1921) generalised to be part of the Kapitian Series.

1.14.2 Previous diatoms research in Kenya and Eastern Africa

Diatoms have been the subject of study in East Africa for over 100 years (West & West, 1896), with these investigations based on modern (Gasse, 1986a, b;

Gasse et al., 1983, 1997; Haberyan, 1992) and the fossil floras (Barker et al., 1990; Owen, 2002; Owen and Crossley, 1992; Owen and Renaut, 2000; Liurkus & Ashley, 2003).

Most of the researches carried out have been on the lakes and lake margins, (Pentecost et al., 1997) or wetland environment (Cholnoky, 1970; Gasse, 1987). The central East African lakes have been the site of intensive diatom research beginning with the investigation of Müller in 1903 and 1910, Forti in 1910 and Hustedt in 1922 (Gasse 1986).

Gasse, 1986 published work on the East African Diatoms' taxonomy and auto ecological catalogue of diatoms found in East Africa from 207 samples and 98 localities situated between 19^0 N and 14^0 S in Latitude, 27 ^{0}E and 43^0 E in longitudes.

Diatoms from Kenya were the subject of Mölder publications from 1961 and Cholnoky was the first author to publish quantitative analyses of diatom communities from Mt. Kenya, the Ruwenzoris Mountains and the Bangweulu swamps (Chonolky, 1960a, b; 1964; 1970).

Feibel et al (1991) analysed diatoms species from Turkana region and found that the dominant specie was *Melosira* cf. *M. granulata* with *Surirella* sp. as secondary component. The interpretation was that the flora was typical of small, shallow or turbid fresh water lakes as well as the littoral areas of larger lakes. Some areas were dominated by *Coscinodiscus sp*. which is characteristic of littoral or bottom mud of closed lakes, generally moderate to high alkalinity and moderate pH.

Halfman et al (1992) analyzed a 12 m sediment core recovered from the south basin of Lake Turkana, north-western Kenya, and revealed four dominant diatom assemblages namely *Melosira nyassensis Stephanodiscus spp.*, *Thalassiosira rudolfi* and *Surirella engleri*.

1.14.3 Mid-to-late Holocene Paleoclimate of Eastern Africa

Africa has experienced significant climatic variation during the late Holocene, (Nicholson, 1981; 1998; Verschuren et al., 2000) some studies have concentrated on longer timescales (e.g., Coetzee, 1967; Livingstone, 1967; Maitima, 1997) some on shorter time scales (Lamp et al, 2003). Changes recorded between glacial to interglacial period follow global climatic changes inferred from astronomical theory whereas the Holocene climatic pattern seems mainly driven by the monsoon mechanism.

During the past five years exciting new results have been generated from the studies of cores from Lake Victoria, which have shown that the lake completely dried up in the Late Pleistocene (Johnson et al, 2002). The recent history of human impact on the lake basin is also clearly discerned in the sediments that have accumulated in the lake during the past century, Verschuren et al., (2001) High-resolution analyses of the elemental composition of calcite and biogenic silica (BSi) content in piston cores from Lake Edward, equatorial Africa, document complex interactions between climate variability and lacustrine geochemistry over the past 5400 years (Russell et al., 2005). Correlation of these records from Lake Edward to other climatically-forced geochemical and lake level records from Lakes Naivasha, Tanganyika, and Turkana has made it possible to develop a chronology of drought events in equatorial East Africa during the late Holocene. These events are superimposed on a long-term trend of increasingly arid conditions from 5400 to about 2000 cal year BP, followed by a shift toward wetter climates that may have resulted from an intensification of the winter Indian monsoon (Russell et al., 2005).

Evidence for the Younger Dryas event in tropical Africa has also been documented in the sedimentary sequences from Lake Albert, Ruwenzori Mountain, Fort Portal area and Lake Victoria have been studied by various researchers for one or more proxies including pollen, diatoms, algae, charcoal, magnetic susceptibility, organic carbon, biogenic silica and water content (Ssemmanda & Vincens 2002). The results show revealed the period from;

10000-14000 to 9500-9900 cal yr BP., saw the widespread of open vegetation and low lake levels attest a dry climate; from 9500 to 6500 cal yr BP., the development of forests and the rise in lake levels inferred from many of the sedimentary records in the two regions indicate a humid Early Holocene; At 6500 cal yr BP., a decrease in rainfall or an increase in the duration of the dry period occurred. As a result of this change, the forests in the two regions acquired semi-deciduous character; at about 3000 yr BP., the forests declined suggesting a dry climate. During the period 3000 to 1700-1000 cal yr BP., the high altitude suggests an increase in precipitation; From 1700-1000 cal yr BP. onwards, indicates the extension of open vegetation originally initiated by a change to drier climatic conditions, has been aggravated by anthropogenic activities.

Using pollen-inferred precipitation time-series from equatorial mountains Bonnefille et al., (2000) estimated the mean paleoclimatic annual rainfall in the equatorial highlands of Central East Africa to have been fluctuating for the last 40,000 yr BP; During the last glacial period (30,000 to 15,000 yr BP interval results show 450 mm/yr (32%) precipitation decrease relative to the present two maxima decrease periods registered at (19,000 yr BP) 700 mm/yr, (45%) and between (18,000 and 16,000 yr BP) 608 mm/yr, (42%); Several abrupt positive peaks of higher precipitation were noticed before 35,000 yr BP and 22,000–20,000 yr BP. During the lower Holocene (10,000–7,000 yr BP.), the mean calculated precipitation estimate was 30 mm/yr (2%) below the present-day value, with several abrupt positive shifts the maximum at 8,000 yr BP reaches 600 mm/yr (42%).

High resolution studies of past climate change in Lake Naivasha, reconstructed the history of regional rainfall variation in the core and interpreted variations in the sedimentary facies and their contained diatom (Verschuren et al. 2000).

Barthelme (1981) studied the geo-archaeology of the late Pleistocene –Holocene sediments along northern side of Lake Turkana with a view of identifying the number and magnitude of Holocene transgressive-regressive cycles. His doctoral thesis indicates that the African continent has undergone considerable

climatic changes during the past 20,000 yr BP. The radiocarbon dates indicates that approximately 12,000 yr BP, the lake levels were higher than today in many parts of Africa (Butzer et al., 1972). Barthelme argues that his and other regional studies in North Africa (e.g. Faure 1966; Servant, Servant and Delibrias 1969: Maley 1977; Williams and Adamson 1974), and Ethiopia (Grove et al., 1975; Street and Grove 1979; Gasse 1975) have identified a number of lake level changes throughout the Holocene.

Ricketts et al (1998) compared oxygen isotope profiles from authigenic calcite, in nine freeze cores from Lake Turkana with the historical record of lake levels for the past 105 years

Lake Malawi has shown a distinct Little Ice Age signal in tropical Africa.
More recently, Gasse et al. (2002) have demonstrated that Lake Malawi was at a low stand during the Last Glacial Maximum (LGM) like all the African lakes in the northern hemisphere, as opposed to previous views.

Preliminary results from Ethiopia show that recent sedimentary records registered the story of famines and droughts since the last centuries. Lake hydrological models will help to determine the hydrological thresholds as associated to major changes in landuse during the Holocene (Legesse, 2003).
1600 years ago, in Lake Massoko (Tanzania), asynchronous changes in hydrology/erosion and vegetation/biomass fires are observed. They preliminary indicate that the lake-basin ecosystem, at the time of iron-age deforestation, needed several tens of years to equilibrate with climate change.

Tropical climate fluctuates on various time scales, from interannual (exemplified by the strong 1997–1998 El Niño) to thousands of years such as the greening of the Sahara from about 10,000 to 5500 years ago Gasse, (2002). At the millennial time scale, Thompson et al (2000) distinguish two climate phases' conditions warmer and wetter than today from about 11,000 to 4000 years ago, and a relatively dry and cool climate over the past 4000 years, Gasse, (2002).

CHAPTER TWO

MATERIALS AND METHODS

The details of the field site and the collection of the core material which were employed to achieve the objectives of the project from Ondiri Swamp are well illustrated here. The laboratory-based procedures used in the preparation of sediment samples and analyses of inorganic and organic matter content are also described.

Also included is a description of the criteria used in the identification of the diatoms species analysed. The procedures used in clustering and zoning sediment based data are also presented.

2.1 Field work

Sediment cores were collected from Ondiri swamps during fieldwork in May 2007. The cored sites were two with Core 1 located at 0° 15' 0.79'' S and 36° 39'22.93''E and Core 2 located at 0° 15' 2.16'' S and 36° 39'26.24''E (Figure 2.2). The core was collected at the centre of the swamp about ten metres from the edge. The swamp is about one kilometre long though it fluctuates during the dry seasons and when the inhabitants draw water for irrigation.

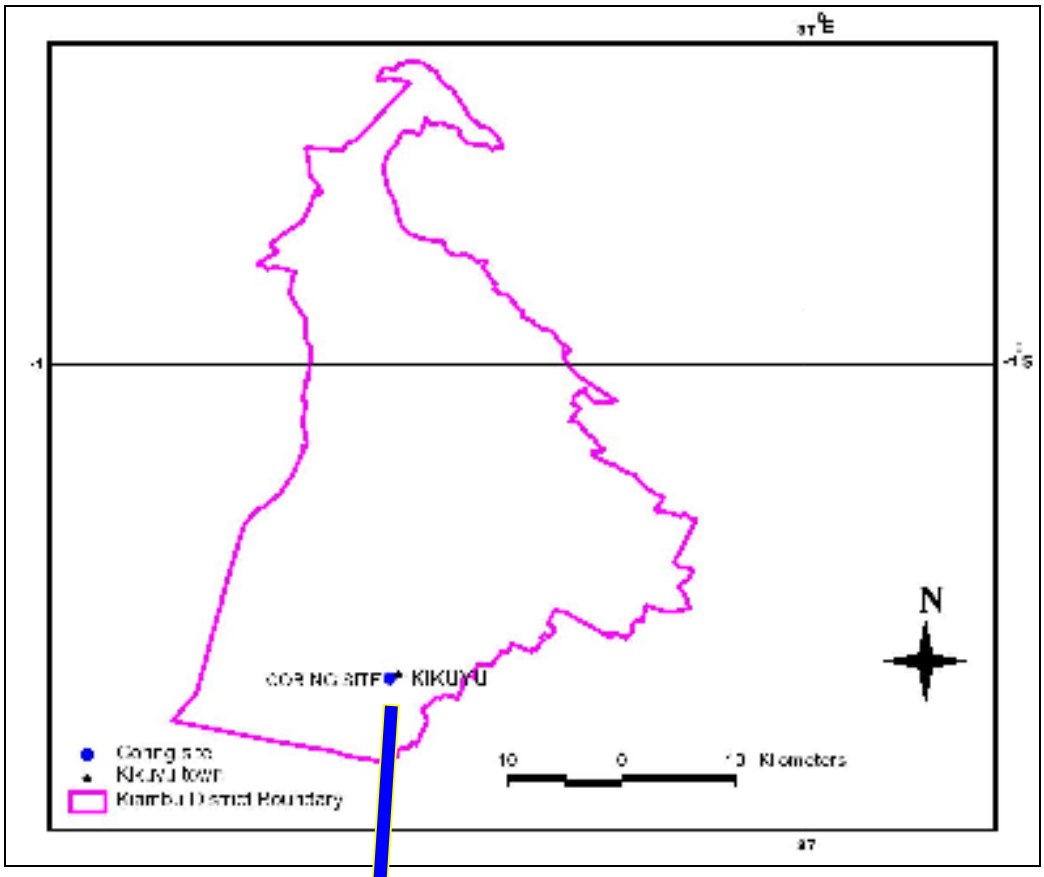


Figure 2.1 Locations of Coring Sites (Kiambu District- Redrawn from Afri cover ILRI-UNEP 2000)

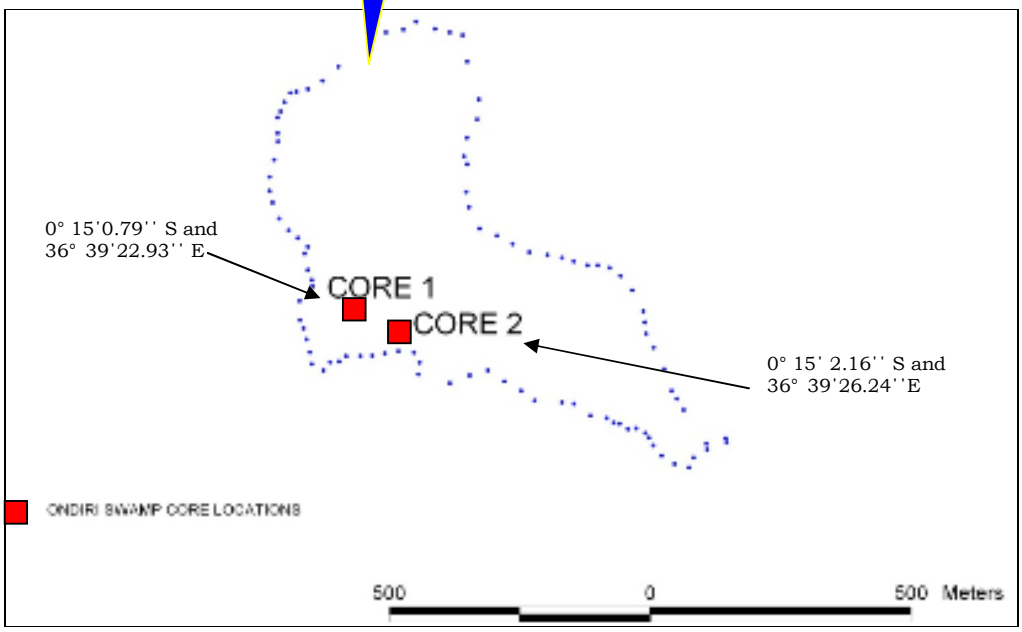


Figure 2.2 Coring Sites at Ondiri Swamp

2.2 Sediment coring

The coring was carried out using Russian corer (Plate 2.1 a) and 2.1 b). The corer measures 5 cm in diameter and 50 cm in length with a sample volume of 10 cubic centimetres. It has a side-filling sampler that collects uncompressed or shortened cores during recovery of samples from swamps or wetlands. The corer was cleaned with distilled water before coring to avoid contamination to the next level (Plate 2.1b).

Plate 2.1a) Russian Peat Corer

Plate 2.1b) Russian Peat Corer being cleaned before coring

Cores were sub-sampled at 5cm intervals and processed for use in the standard diatom concentration (Plate 2.2 a) and 2.2b).

Plate 2.2 a) and 2.2 b) Sectioning and partitioning of the cores of 5 centimetres

Description of the lithological characteristics of the recovered cores was done in the field and the core with the most varied laminations in the column was picked for analysis in the laboratory (Core 2-Plate 2.3a).

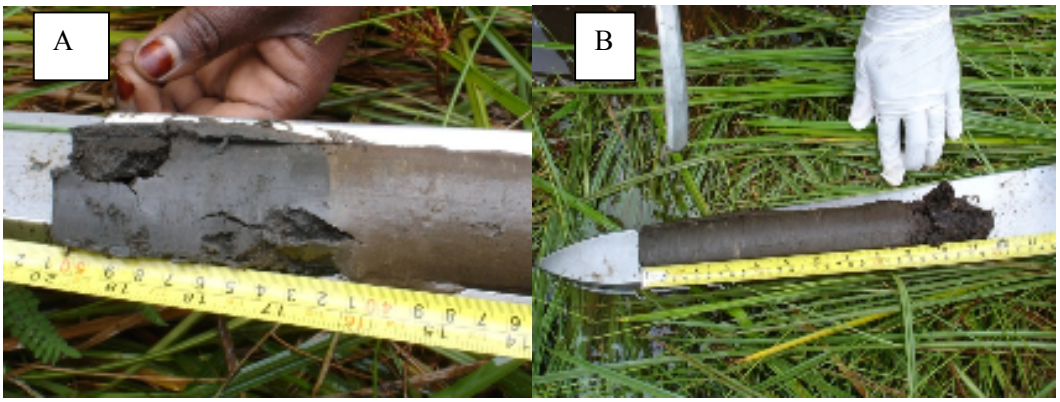


Plate 2.3a) Core 2-with varied laminations and Plate 2.3b) Core 1- with less varied laminations (poor recovery)

Later the sediments were transferred into 50cm plastic bags sectioned in half (Plate 2.4.a) and 2.4b), wrapped using aluminium foil, and transported to the Palynology Department at the National Museums of Kenya.

Plate 2.4a) and 2.4b) Sub-sampling and labelling of sample bags

2.3 Preparation of diatoms for analysis

Diatom cleaning techniques used by Kelly, (2000), Round et al., (1990), Gasse, (1986 a, b), Krammer & Lange and Bertalot, (1986, 1988, 1991a, b) and Leng, and Baker, (2006) was employed to avoid diatom damage. Sample of about one cubic centimetre were cleaned by treatment with 5% hydrochloric acid and 30%

hydrogen peroxide to remove contents of carbonates and organic matter (See Figure 2.3).

Shemesh et al., (1995) and subsequent papers describe a methodology that by adding a heavy liquid settling (like STP which is not available in the country and is quite expensive) stage to separate diatoms from remaining clastic grains. Due to lack of such a heavy solution to totally remove the sediment, it proved impossible to get 100% pure diatom samples when silt of a similar size to the diatoms is the major contaminant but a solution of Ammonia was used instead.

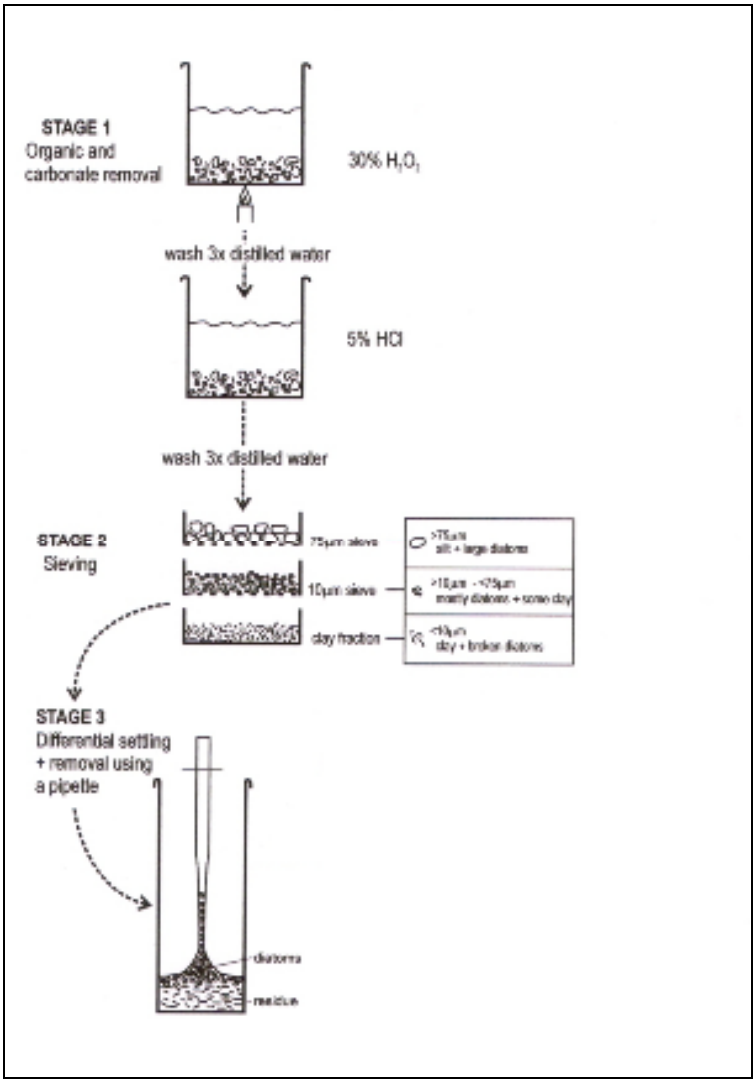


Figure 2.3: Flow diagrams showing the stages of cleaning method for diatom analysis from swamp or lake sediments. Redrawn from Leng and Baker (2006)

2.3.1 Diatom identification and counting

The prepared diatom samples were mounted on glass slides with Naphrax and examined under oil immersion Leitz Dialux 20EB light microscope. The diatoms were counted under x400 magnification; detailed features were examined under x1000 magnification.

Taxonomic classifications and identifications were made according to Gasse (1986), Kelly (2001), Krammer & Lange-Bertalot (1986, 1988, 1991a, b), Germain (1981) and Sims (1996). Since most frustules were separated it was convenient to count each valve as a unit and digital photographs of diatoms assemblages taken. Identification of diatoms species was made to the lowest possible taxonomic level, although some species could only be identified to family level. The counting started at the centre of the slide towards the edge at least 400 diatoms grains were counted from each slide, except in a few samples where preservation was poor.

Samples rich in clay and sand particles had very few or no diatoms resulting in gaps in the diatom record. All the counts were probably underestimates of true abundance as the diatoms with more rapid settling ability or larger ones were able to be counted.

2.4 Determination of Moisture Content

Fourteen wet samples of approximately of 0.5-1 grams were weighed from each stratigraphic sub-sampled level. The samples were dried for 12 hours at 105°C in an oven and later cooled to room temperature. The moisture content was determined by the difference in weight between the freshly extruded samples and the dried samples and results presented as a percentage of the wet over dried weights (Appendix eight).

2.5 Determination of Total organic Content (Organic Matter)

Fourteen wet samples of approximately of 0.8-1.5 grams were weighed from each stratigraphic sub-sampled level. The samples were ignited in a muffled furnace for 12 hours at 550° C cooled in a desiccator and re-weighed. The total organic content (T.O.C) was determined by the difference in weight between the freshly extruded samples and the dried samples and results presented as a percentage of the wet over dried weights (Appendix eight).

2.6 Determination of the geochemical content of the sediments

The fourteen soil sediment samples 4-5 grams from different chronological levels were dried at 105° C and taken for geochemical assaying at the Ministry of Environment and Natural Resource-Mines and Geology Department. These analyses were done for full geochemical assay for Oxides of Silica, Aluminium, Calcium, Magnesium, Sodium, Potassium, Carbon, Phosphorus and Iron and Metals of Zinc, Lead, Copper, Chromium, and Nickel.

2.7 Radiocarbon determination

Three samples of organic sediment of about 3 grams were sent to Beta Analytic Inc., Miami, Florida in U.S.A for analysis by AMS Dating techniques. The samples were dried for 12 hours at 105°C to remove all the moisture which would cause moulding and give wrong dates. The samples were packaged in aluminium foil in a well wrapped spongy box before taking for dating. The major criteria used to select the sections to be dated followed the lithological characteristics of the core mainly the sections from the more humus with a lot of charcoal to the more compacted bottom clayer soils.

2.8 Presentation of results

The data were plotted using Tiliagraph Version 2.0.b.S Grimm, (1995). The boundaries of diatom assemblage zones were defined using a stratigraphically constrained clustering procedure (CONISS; Grimm, (1987) and the Edwards and Cavalli-Sforza chord distances used as a dissimilarity measure (Figure 4.1). These zones are entirely based on diatom assemblages within the sedimentary core.

CHAPTER THREE

RESULTS OF SEDIMENT STRATIGRAPHY AND RADIOCARBON DATING

The results of the analyses of sediment stratigraphy and radiocarbon dating of the Ondiri sediment cores and the determinations of the autochthonous and allochthonous sediments are well demonstrated.

3.1 Sediment stratigraphy for Ondiri core

The stratigraphic zonation for Ondiri core is based on description of sediment type (Figure 3.1). The bottom part of the core (47-50cm) is composed of hard compacted clayer sediment with a depth of 9cm. Very soft silty clay with a depth of 18cm describes the second part of the core (41-23cm). The following part has a depth of 8cm (15-23cm) composed of silty clay with fibrous roots and brown, frequent laminations. The uppermost part comprises decomposed clay with organic matter with a depth of 15cm (0-15cm).

When first extruded the upper ten centimetre of the core was highly variable in colour and texture. The upper most sediment was light brown and fluid, becoming slightly gelatinous (semi-solid) after partial drying. The upper one through to ten centimetres were generally moist, with the exception of the hard layer following twenty centimetres which was very dry and composed of layered sand, beneath which was finer sediment partially weathered into soil. Colourful bands and zones characterised many parts of the core from the top through to forty centimetre, these included flecks of white $CaCO_3$, several regions of very smooth grey-brown or grey-black sediment and a number of whitish flocculent zones.

In the lower forty through to fifty centimetres the sediment was very dark and fine but included very thin bands of clay (Plate 3.1).

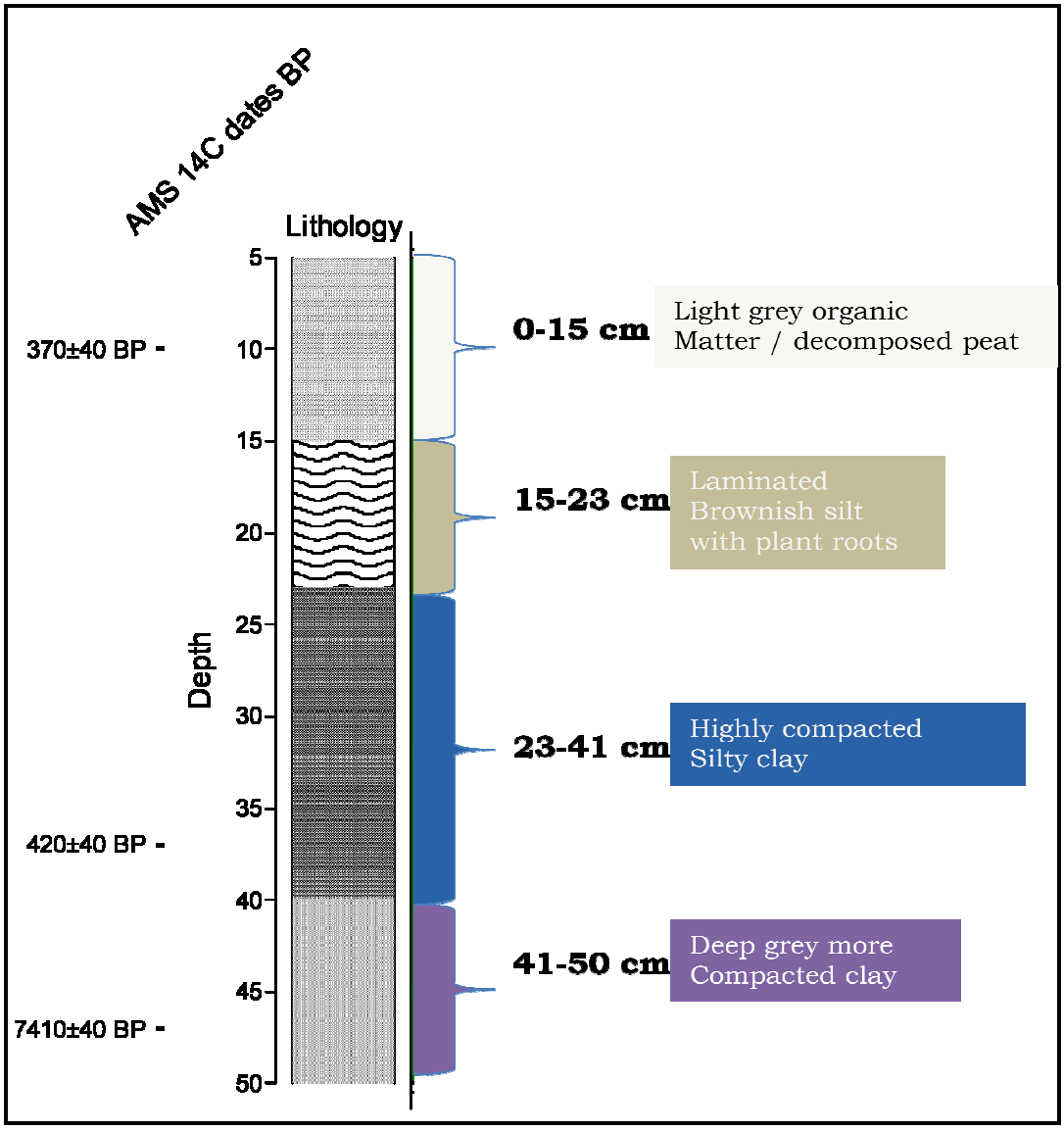


Figure 3.1: Lithology of Ondiri Swamp core

This core probably contains a small fraction of the history of the swamp as the base of the sediment was not reached and the whole section represent a post-glacial time, the near bottom of the core dating to 7410±40 BP.

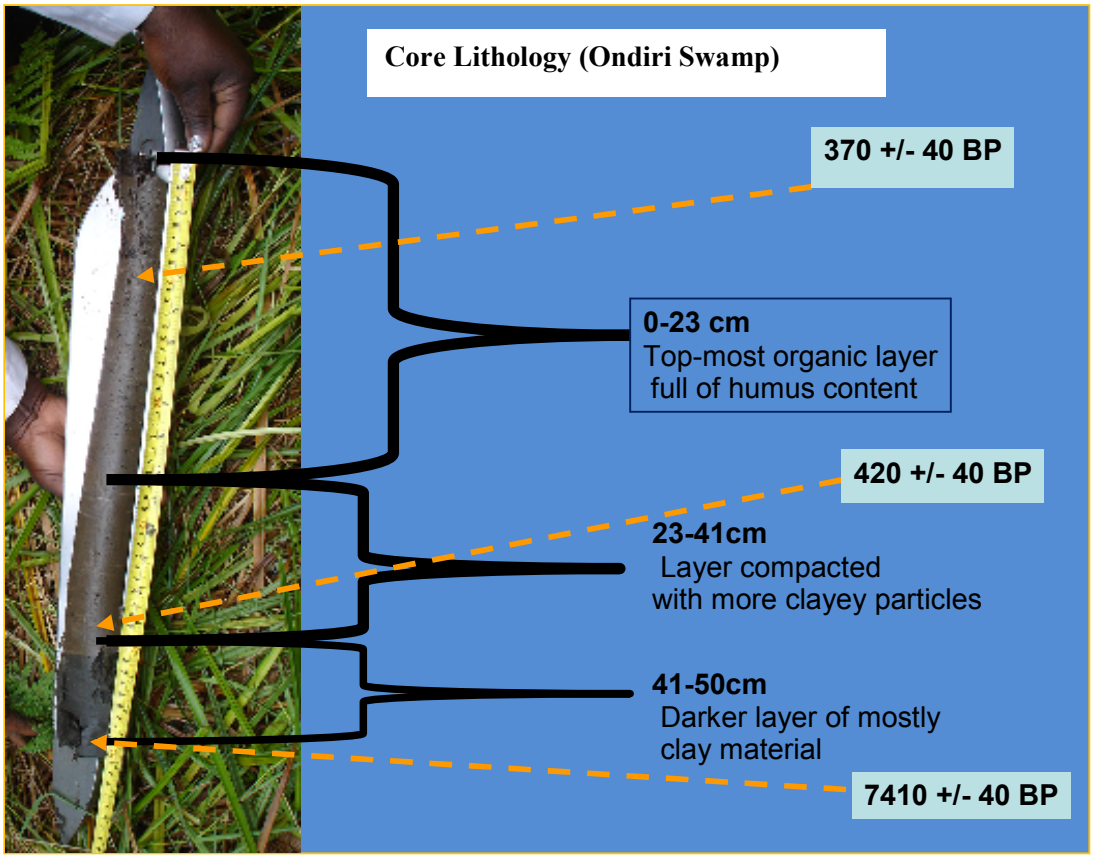


Plate 3.1 Lithology of Ondiri core

3.2 Results of sediment chronology and Age-depth curve for Ondiri Swamp

The results of the AMS ^{14}C dating of samples from Ondiri are presented in Table 3.1. The calibrated dates are reported in yrs BP with 2 sigma calibrated results (95% probability). Of the three samples dated, two AMS ^{14}C ages are stratigraphically consistent from the basement sample of 7410 ± 40 BP (47-50cm) to 370 ± 40 yr BP (5-10cm).

The age-depth curve for the core was based on three AMS ^{14}C dates, 7410±40 yr BP (Cal. BC 6390 to 6220) but the corrected extrapolated value (Figure 3.2) is about 2900 yr BP, 420±40 yr BP (AD 1430 to 1520 and 370±40 yr BP (Cal. AD 1440 to 1640). The AMS ^{14}C data and the age-depth relationship for Ondiri indicate that the core contains a record of past environmental conditions for the last 3,000 yr BP.

The measured carbon isotopic ratios (^{13}C /^{12}C) and δ^{13} C (‰) values for all the samples sediment sent for analysis were -17.5 ‰ (typical for tropical aquatic sediments), -19.9 ‰ and -20.0 ‰ which indicate terrestrial inputs.

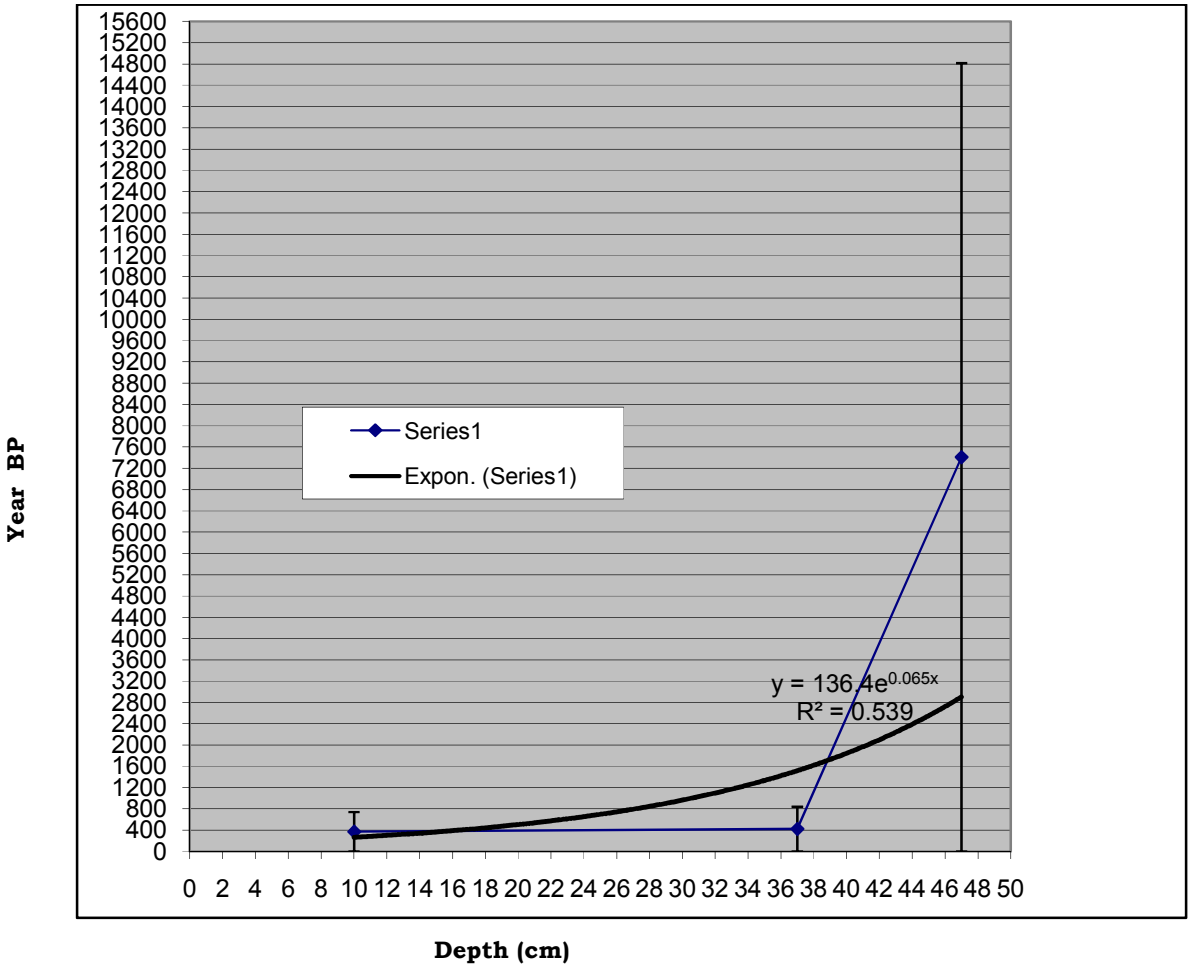


Figure 3.2: Ondiri Age graph curve with a regression curve for the corrections of the dates AMS^{14}C).

Table 3.1. AMS radiocarbon dates and $^{13}C/^{12}C$ ratios ($\delta^{13}C$ ‰) values for Ondiri Swamp core. The AMS dates were calibrated using Calib 4.4 and calibration curve INTCAL 98 Radiocarbon Age Calibration and presented as 2-sigma calibrated age (BC/AD) at 95% probability.

Sediment core	Laboratory Number	Depth (cm)	Conventional ^{14}C age (yr BP) ± 1δ	Calibrated ^{14}C age (Cal BC/AD) ± 2δ	Median Cal. ^{14}C age	^{13}C / ^{12}C $\delta^{13}C$(‰) value	Material dated
JAO-ONDIRI-1 LEVEL 47-50CM	Beta-233135	47	7450-7370 BP	BC 6390 to 6220	-	-17.5 ‰	Organic sediment
JAO-ONDIRI-2 LEVEL 37-39CM	Beta 233136	37	460-380 BP	AD 1430 to 1520	1620 AD	-19.9 ‰	Organic sediment
JAO-ONDIRI-3 LEVEL 10-15CM	Beta 233137	10	410-330 BP	AD 1440 to 1640	510 AD	-20.0 ‰	Organic sediment

CHAPTER FOUR

RESULTS FROM DIATOMS ANALYSIS

The presentation of the results of microfossil diatom assemblage's analysis from sediment cores are described by the down-core variations and an interpretation of the results presented.

4.1 Diatoms Stratigraphy

Fourteen samples from the Ondiri Swamp core were analysed for their diatoms content. One hundred and nineteen species (Appendix one) were identified to genus and family level. All samples were rich and well-preserved diatoms with a total count (excluding damaged grains) ranging between 150 to 400 diatoms.

The recovery of diatoms from the sample levels 47-50cm, 43-45cm, 41-43cm, 20-25cm, 15-20cm, 5-10cm were poor and only counts of <100 grains per sample were possible hence two to three slides were counted. Core samples were grouped according to their non-local diatoms content using stratigraphically constrained techniques of numerical clustering.

Diatoms assemblages that did not attain levels of greater than 2% in any sample were excluded from the clustering process (following the recommendations of Birks & Gordon 1985) and hence only fifty four species were clustered for final analysis. Four diatoms zones were recognized within the diatoms assemblages of Ondiri Swamp, which were labelled Ondiri 1, Ondiri 2, Ondiri 3 and Ondiri 4 from the oldest to the youngest (Figure 4.1)

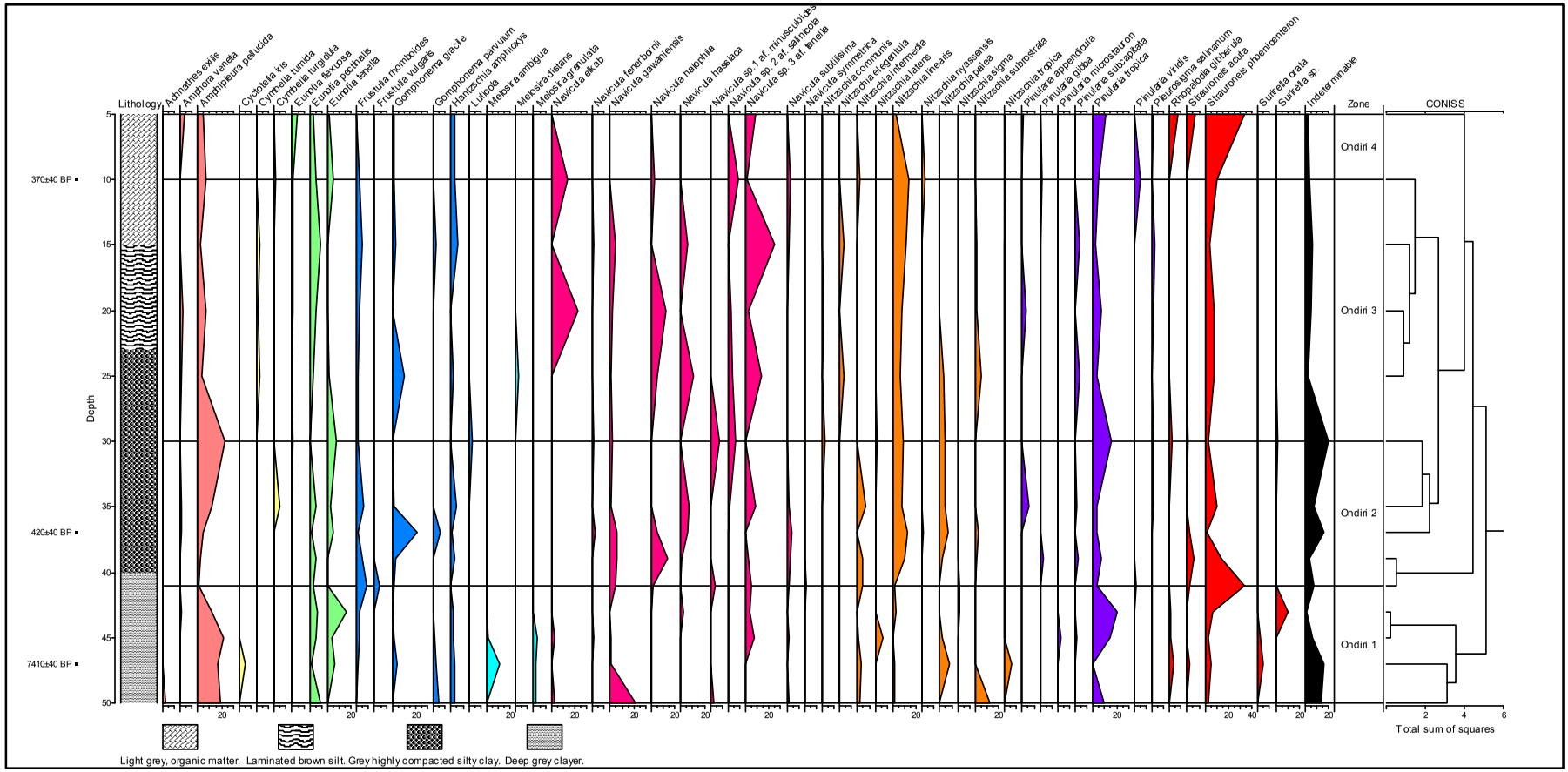


Figure 4.1 Diatoms assemblages and the zonation of Ondiri Swamp (TILIA graph presentation)

Zone Ondiri 1 (41-50 cm) 7410±40 BP

Diatom zone Ondiri 1 extends from the bottom of the core at 50 cm to 41cm and includes stratigraphic zone 1 and has majority of the taxa (Figure 4.1). This diatom zone is dominated by species with values above 20% which included *Amphipleura pellucida* (12.5-22.1%), *Navicula gawaniensis* (0-22.1%) and *Pinularia tropica* (0-21.1%), other species with values ranging from 10-15% were *Eunotia tenella* (0-15.7%), *Melosira ambigua* (0-11.5%), *Nitzschia subrostrata* (0-12.3), *Surirella sp.* (0-10.2%) others species with values from 5-10% but were important in the zone were *Eunotia pectinalis* (2.2-8.4%), *Cyctotella iris* (0-5.4%), *Nitzschia latens* (0-6.1%) and *Strauroneis phoenicenteron* (3.5-7.0%).

Zone Ondiri 2 (30-41 cm) between ages 420±40 and 370±40 BP

Diatom zone Ondiri 2 accommodates the majority of upper part of stratigraphic zone Ondiri 1 (Figure 4.1) with the species *Amphipleura pellucida* (0.8-23.2%), *Gomphonema gracile* (0.6-21.3) and *Strauroneis phoenicenteron* (1.4-33.6%). Species which attained values between 5-10% are *Navicula halophila* (0-13.4%), *Nitzschia linearis* (2-12.8%) and *Pinularia tropica* (2.8-15.2%) others with values between 5-10% were *Eunotia pectinalis* (1.1-5.8%), *Eunotia tenella* (0-6.9%), *Frustulia rhomboides* (0.4-8.3%), *Gomphonema parvulum* (0-6.4%), *Navicula hassiaca* (0-6.5%), *Navicula minusculoides* (0-8.0%), *Navicula salinicola* (0-6.9%), *Nitzschia intermedia* (0-6.5), *Nitzschia palea* (0-7.4%) and *Pinularia appendicula* (0-5.5).

Zone Ondiri 3 (10-30 cm) 420±40 BP

Diatom zone Ondiri 3 extends from 30cm to 10cm of the core. The zone is dominated by (Figure 4.1) *Navicula tenella* (2.2-24.5%) and *Navucula el Kab* (0-22.0%), other species with 10-15% were *Nitzschia linearis* (6.4-14.3%), *Navicula halophila* (0-13.0%), *Gomphonema gracile* (0.4-10.1) and *Strauroneis phoenicenteron* (4-10.1%), the species with values between 5-10% were *Pinularia tropica* (2.1-6.9%), *Navicula salinicola* (0-8.4%), *Frustulia rhomboides* (0.9-5.1%), *Eunotia pectinalis* (2.4-8.8%), *Amphipleura pellucida* (2.4-6.9%) and *Hantzschia amphioxys* (0-5.6%).

Zone Ondiri 4 (10-0 cm) 370±40 BP

Diatom zone Ondiri 4 extends from 10cm to the top of the core. The zone had very few species dominance and variations within its valuation, the most dominant specie (Figure 4.1) was *Strauroneis phoenicenteron* (34.2 %) and others were *Navicula tenella* (8.0%), *Pinularia tropica* (11.2%) and *Rhopalodia gibberula* (6.6%).

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4.2 Modern analogues of the fossil diatoms at Ondiri Swamp

Diatoms can be used to trace a variety of environmental phenomena, from changes in sea level (whether brought about by climate change or tectonic activity), breaches of coastal barriers (as a result of storms and/or sea-level rise), to the evaporation of lakes (increasing salinity) determining diatom assemblages. Fossil diatoms at Ondiri Swamp were compared to their extant communities with guidance from information from published literature Kelly (2000), Round et al., (1990) Gasse (1986), Krammer & Lange and Bertalot (1991) and Leng, et al., (2006).

The diatoms at Ondiri Swamp were grouped into various preferences to water chemistries, including alkalinity (Appendix two), water pH (Appendix three), and conductivity (Appendix four), the data being compared to the modern analogues from various areas in Eastern Africa.

Diatoms were also grouped in various ecological preferences (Appendix five) which they best thrive and this is vital for the interpretation of the ecology of a wetland.

4.2.1 Analogues of modern water pH preference of fossil diatoms assemblage's at Ondiri Swamp

The diatom assemblages were grouped into to the most preferred pH ranges and this trend showed that the diatoms thrived best at extremely acidic condition and extremely alkaline conditions (Figure 4.2).

In Acidic conditions

Ondiri core diatoms species that prefer lower pH were *Pinularia subcapitata, Pinularia tropica, Cymbella turgidula, Navicula plateneis, Strauroneis phoenicenteron, Eunotia Montana, Eunotia tenella, Eunotia veneris, Strauroneis acuta, Amphipleuria pellucida, Eunotia flexuosa, Melosira ambigua, Pinularia appendicula* and *Pinularia microstauron* (Figure 4.2).

In Circum-neutral conditions

Diatoms which prefer pH 7 or circum neutral pH (Figure 4.2) were *Navicula salinicola, Nitzschia elegentula, Nitzschia nyassensis, Hantzschia amphioxys, Navicula bryphila, Navicula hassiaca, Navicula subtilisima and Nitzschia linearis*.

Slightly alkaline to strongly alkaline conditions

The rocks at Ondiri Swamp are mostly Alkaline and this may have a great influence on the water chemistry hence the species that preferred this range of pH are expected to be numerous. From literature analysed *Pinularia gibba, Achnathes exilis, Cymbella tumida, Navicula fenerborn*ü,

*Nitzschia subrostrata, Frustulia vulgaris, Surirella ovata, Melosira granulata, Navicula gawaniensis, Navicula halophila, Navicula minusculoides, Rhopalodia gibberula, Cyclotella iris, Nitzschia communis, Surirella sp.*1, *Eunotia pectinalis*, *Frustulia rhomboides*, *Navicula symmetrica*, *Amphora veneta*, *Nitzschia intermedia*, *Nitzschia palea*, *Synedra acus*, *Synedra acus, Rhopalodia gibberula*, *Cyclotella iris, Nitzschia communis, Surirella sp.*1 and *Pinularia appendicula* were observed to prefer this pH ranges (Figure 4.2).

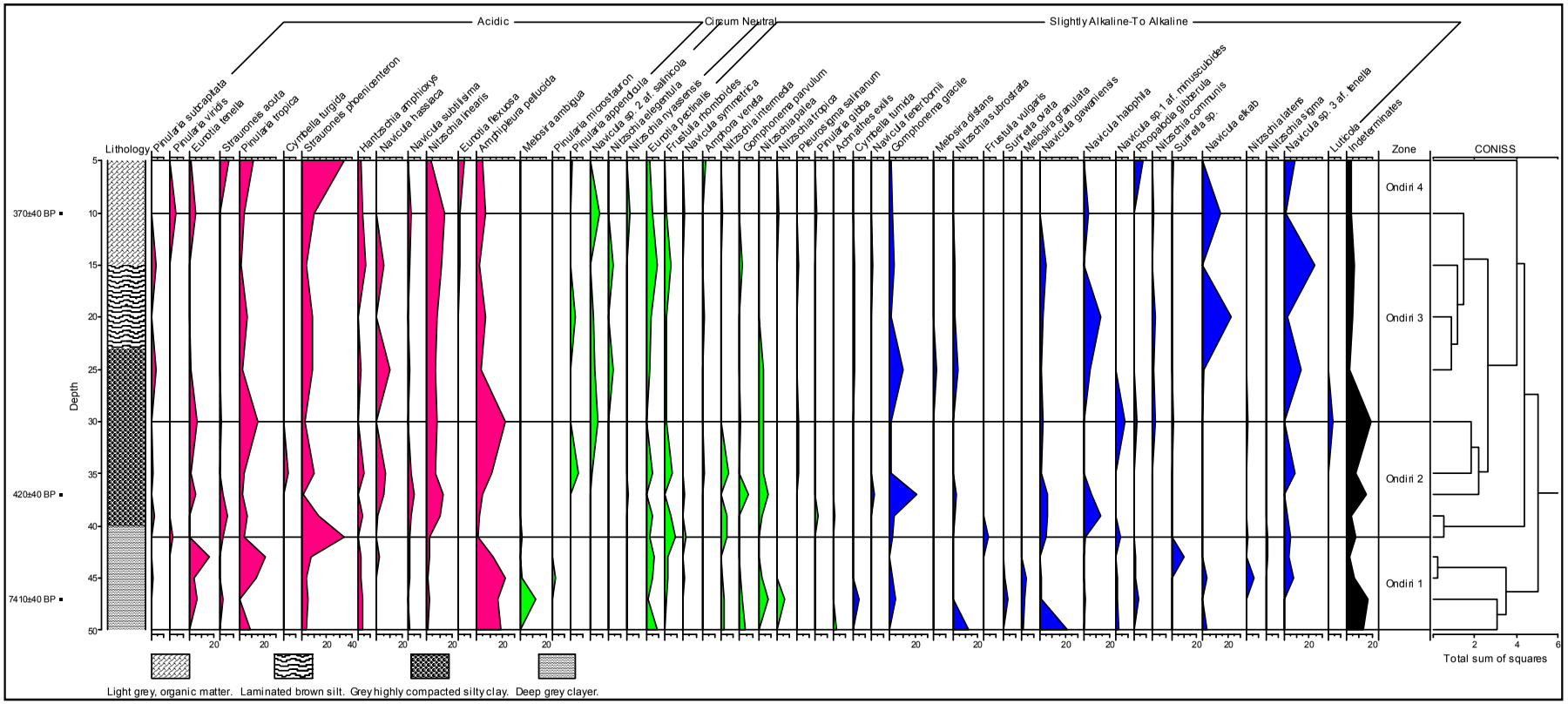

Figure 4.2 Diatoms Communities relationship with changes pH in Ondiri Swamp

4.2.2 Analogues of modern water temperature preference and comparison to the fossil diatoms assemblage's at Ondiri Swamp

Temperature effect on diatom growth may be both direct and indirect. Some species have narrow temperature range and others are able to withstand large ranges of temperature. The dominance or the development of a large population of a given species seemed to be quite related to the temperatures, some species would prefer cool water conditions while others under warmer temperatures (Appendix seven). The diatom assemblages of Ondiri Swamp core were grouped in to the most preferred temperature ranges (Figure 4.3) and it was clear that diatoms concentrations were not affected by ranges of temperatures.

Temperatures of between 10- 27 ^{0}C

Most of the species preferred this range of temperature maybe because of the general climatic condition which has been prevalent from the past. The species here included *Pinularia subcapitata, Navicula bryphila, Navicula subtilisima, Navicula hassiaca, Frustulia rhomboids, Eunotia flexuosa, Pinularia gibba, Hantzschia amphioxys, Frustulia vulgaris, Pinularia tropica, Navicula symmetrica, Nitzschia lateens, Pinularia microstauron, Amphora veneta, Nitzschia palea, Synedra acus, Achnathes exilis, Strauroneis phoenicenteron, Nitzschia tropica, Nitzschia linearis, Cymbella tumida* and *Cymbella turgidula* (Figure 4.3).

Temperatures of above 28 ^{0}C

These are extreme temperature conditions and very few species were observed to tolerate such higher temperatures including; *Navicula el Kab, Nitzschia sigma, Nitzschia intermedia, Nitzschia subrostrata, Cyclotella iris, Nitzschia communis, Pleurosigma salinanum, Navicula fenerbornii, Navicula gawaniensis, Rhopalodia gibberula* and *Melosira granulata.*

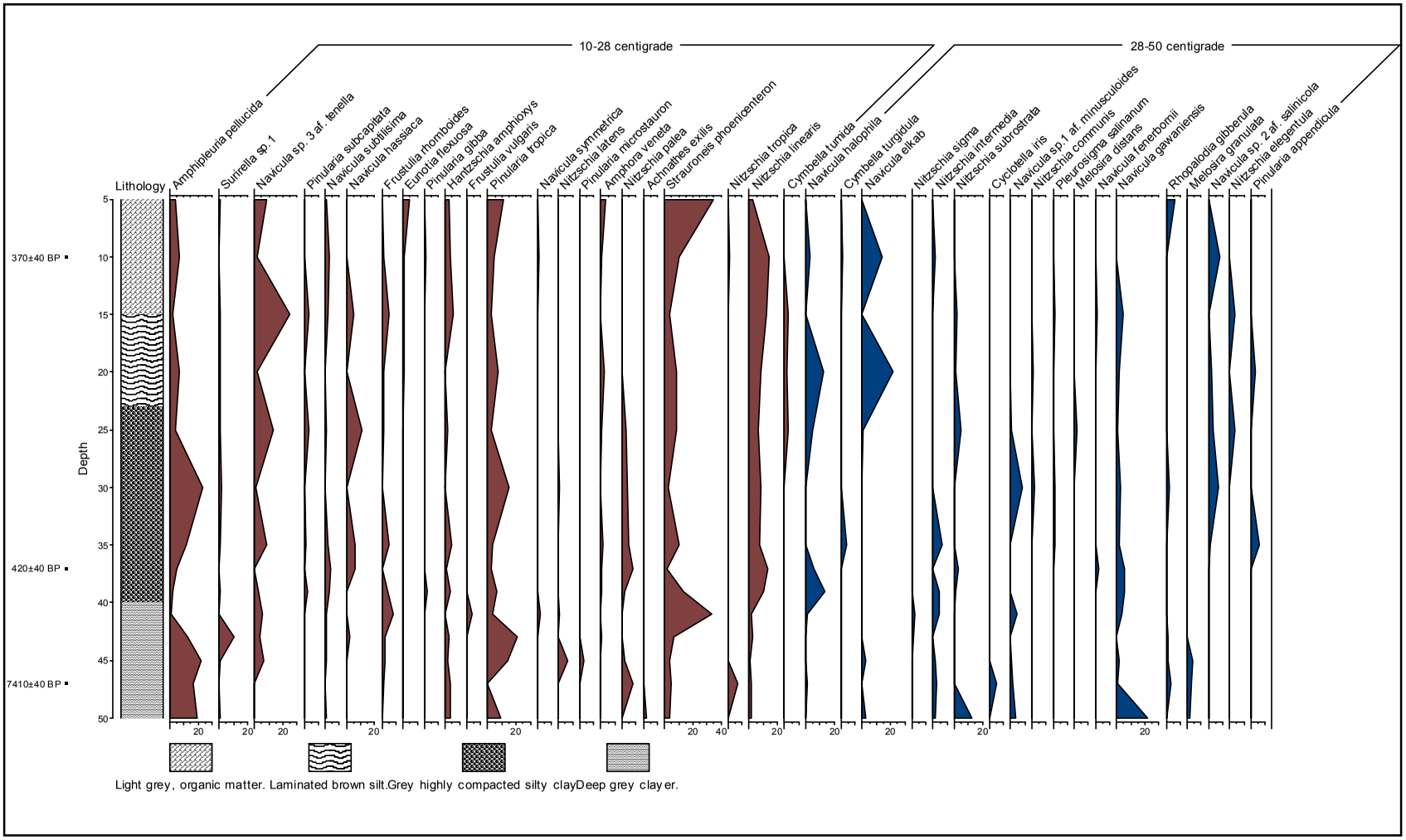

Figure 4.3 Temperature preferences for diatoms of Ondiri Swamp Core

4.3 Recent vegetational changes at Ondiri swamp

The vegetation change at Ondiri Swamp as reported by Kinyanjui (2003), at the levels 105cm -90 cm was dominated by grass (Poaceae) shrubs (*Astreraceae, Amaranthaceae/ Chenopodieceae*) pollen. Low counts of tree taxa pollen and only *Podocarpus* and Mimoseceae were noted (Figure 4.4). This core may be of very recent age ~200 yr. BP or less derived from the lithology and the vegetational types of the core (Personal communication from the field assistant) and it was recovered at the periphery of the swamp.

The next level was at 85 cm- 75cm, where there was increase in both terrestrial and aquatic vegetation though a drastic drop is observed at the levels 75cm – 65cm indicating sudden reduction on the vegetation cover. The grass (Poaceae) shrubs (*Astreraceae, Amaranthaceae/ Chenopodiaceae*) pollen was still dominant.

From 65 cm to the topmost layer the main dominant species were *Eucalyptus* and *Juniperus/Cupressus* an exotic species. *Zeamays* (maize) pollen is also observed in significant quantities at this zone. *Podocarpus* and *Olea* pollen presence suggests long distance transport rather than their presence in the swamp (Kinyanjui, 2003).

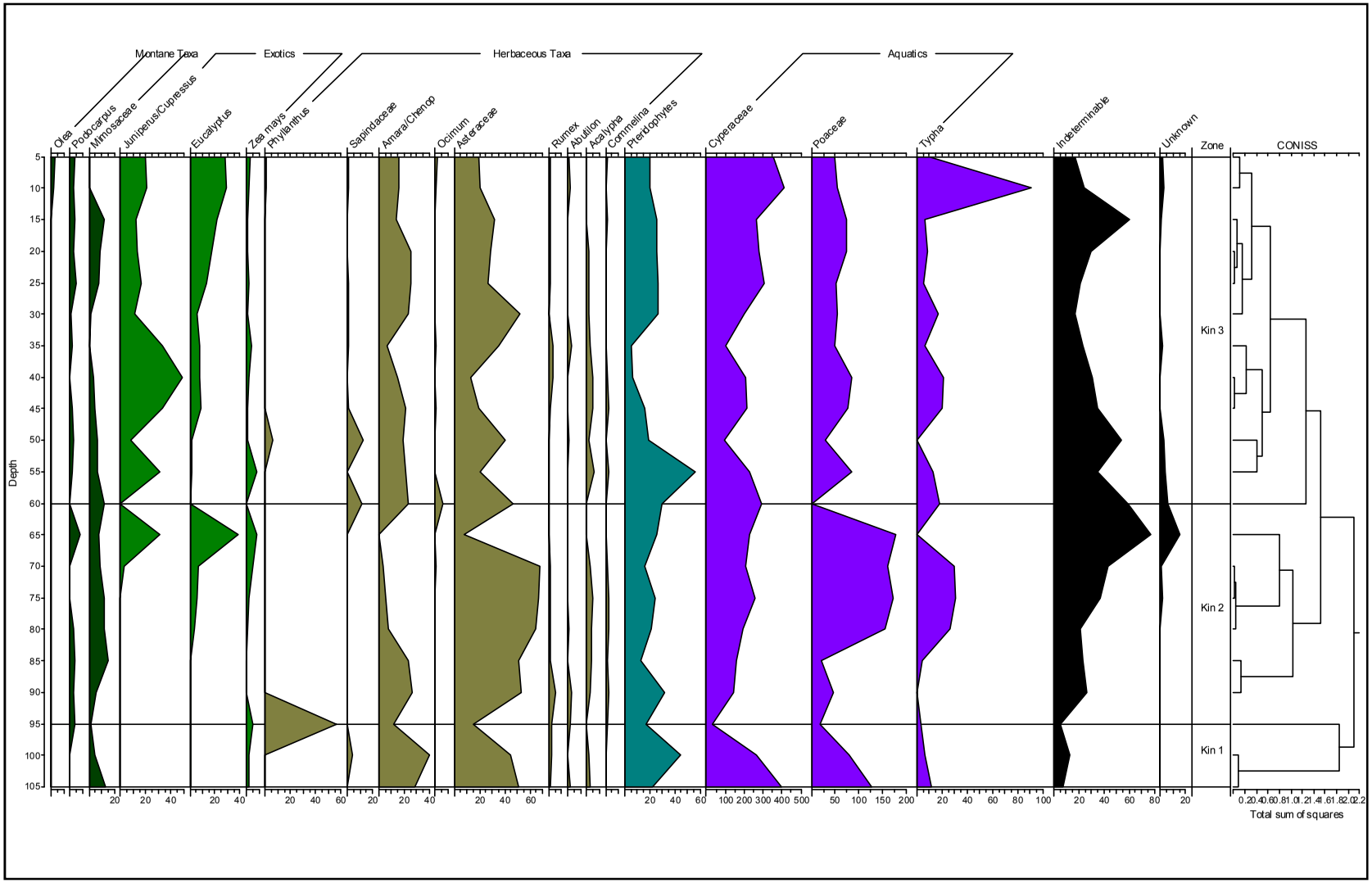

Figure 4.4 Pollen Diagram for Ondiri Swamp (Modified from Kinyanjui, 2003)

CHAPTER FIVE

RESULTS FROM GEOCHEMICAL ANALYSIS

The results of geochemical analysis from sediment cores are described by the down-core variations and an interpretation of these results presented.

5.1 The Moisture Content of Ondiri Swamp core sediments

Moisture content decreased fairy steadily with depth attaining a maximum at depth at 10-15cm (68%) and a minimum at the depth of 47-50 (32%). Except for the two sharp increases i.e. levels 10-15cm (68%) and 30-35cm (62%) and sharp decrease at level 35-37 (42%), which reflect changes in the nature of sediment (Figure 5.1), the sharp changes in moisture content may be attributed to the contamination during collection by the either excess water getting trapped during processes of collection or bagging because this layer contains a lot of humus content which may attract moist air (raw data in Appendix eight).

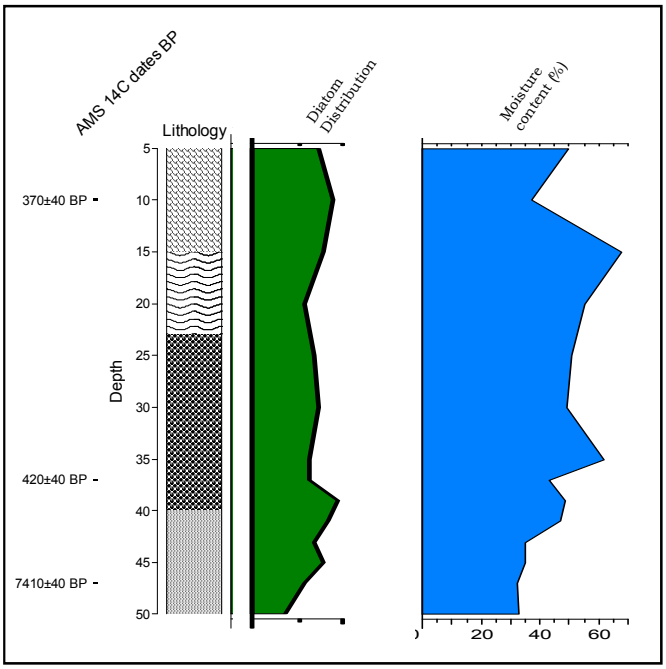

Figure 5.1 Moisture content of the sediment of Ondiri Swamp Core

5.2 The organic matter of Ondiri Swamp core sediments

The Total Organic Matter (TOC) decreased steadily with depth with a slight increase at level 5-10 cm (55.7%) and 10-15cm (55.12%) and abrupt peak at level 43-45 (52.44%) cm (Figure 5.2). The increase at level 43-45cm may have risen because of contamination within the most compacted clay layer. The highest level of organic content recorded was at level 10-15cm at (55.7%) organic content (raw data in Appendix eight).

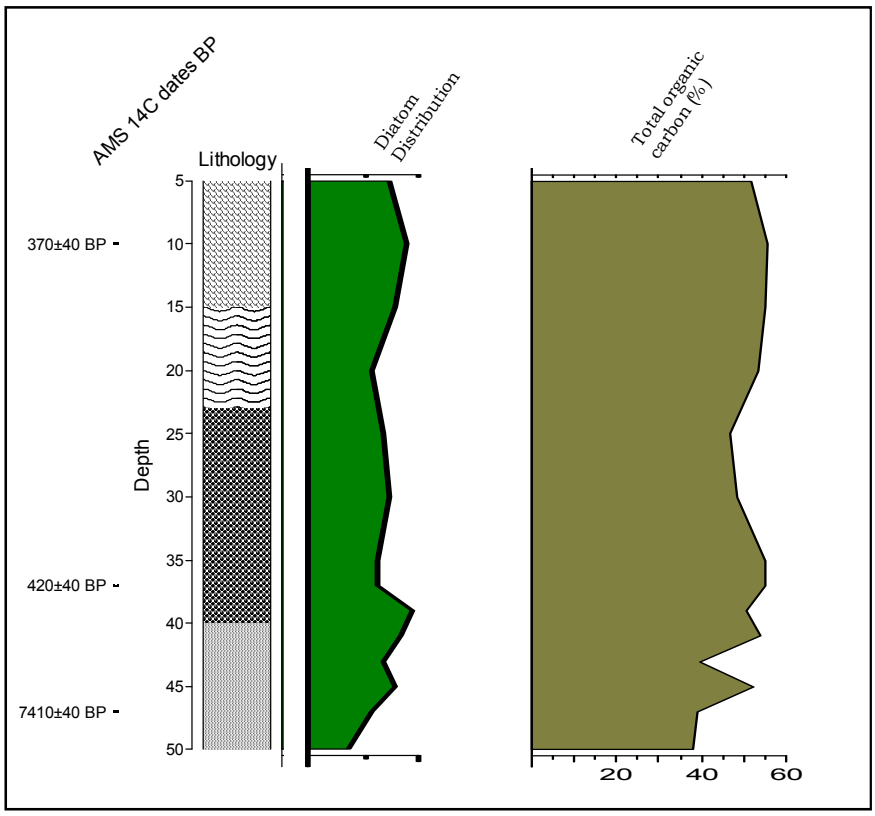

Figure 5.2: The organic matter content of Ondiri Swamp core

Stratigraphic variation in organic content may reflect changes in

i) Biological productivity of the swamp
ii) Amount of terrestrial organic matter entering the swamp
iii) Of preservation of organic mater

iv) And the concentrations of inorganic materials (Richardson et al., (1972)

The sedimentation rates (rate of accumulation per year) for the three carbon dated intervals of the core with a margin error of ±40 years as represented in Table 5.1.

Table 5.1 Rates of deposition of wet and dry organic matter in different parts of the core

Stratigraphic Ages (Yr. BP)	Core interval (cm below mud surface)	Depth of wet sediment deposited per year (g/cm)	Average dry weight of 1cc of wet sediment (g)	Dry sediment deposited per year (g/cm^3)	Average organic content (%)	Organic matter deposited per year(g/cm^3)
370±40	0-10	0.027	0.964	0.00384	53.83	0.002067
420±40	10-37	0.54	0.81914	0.10076	52.037	0.05243
7410±40	37-50	0.00186	0.6428	0.00039	44.574	0.000174

For the past 370±40 yr BP, the average rate of deposition of both dry sediment and organic matter has been significantly been lower than during the preceding 7410±40 yr BP years (Represented by the two lower intervals). The low organic percentages recorded for the bottom part may not be an indicative of low organic productivity or poor preservation, but reflect rapid sedimentation rate.

5.3 The geochemistry as an indicator of past geological chemistry of Ondiri Swamp core

All geological events within the past times are archived within the sediments which give great details of the organic and inorganic matter. For Ondiri core, the metals and metal oxides which were analyzed to determine their concentrations were five including trace elements of Zinc, Lead, Copper and Nickel and oxides of Silica, Aluminium, Calcium, Magnesium, Sodium, Potassium, Carbon, Phosphorus and Iron (Ferrous oxide).

Their general trend with increasing depth is varied for each and every element or oxides of the element (Figure 5.3). Some values of metals were affected by other showing a relationship within their concentrations. Other values were altered with increasing depth of the core. The trend for each element or oxide is individually in detail below.

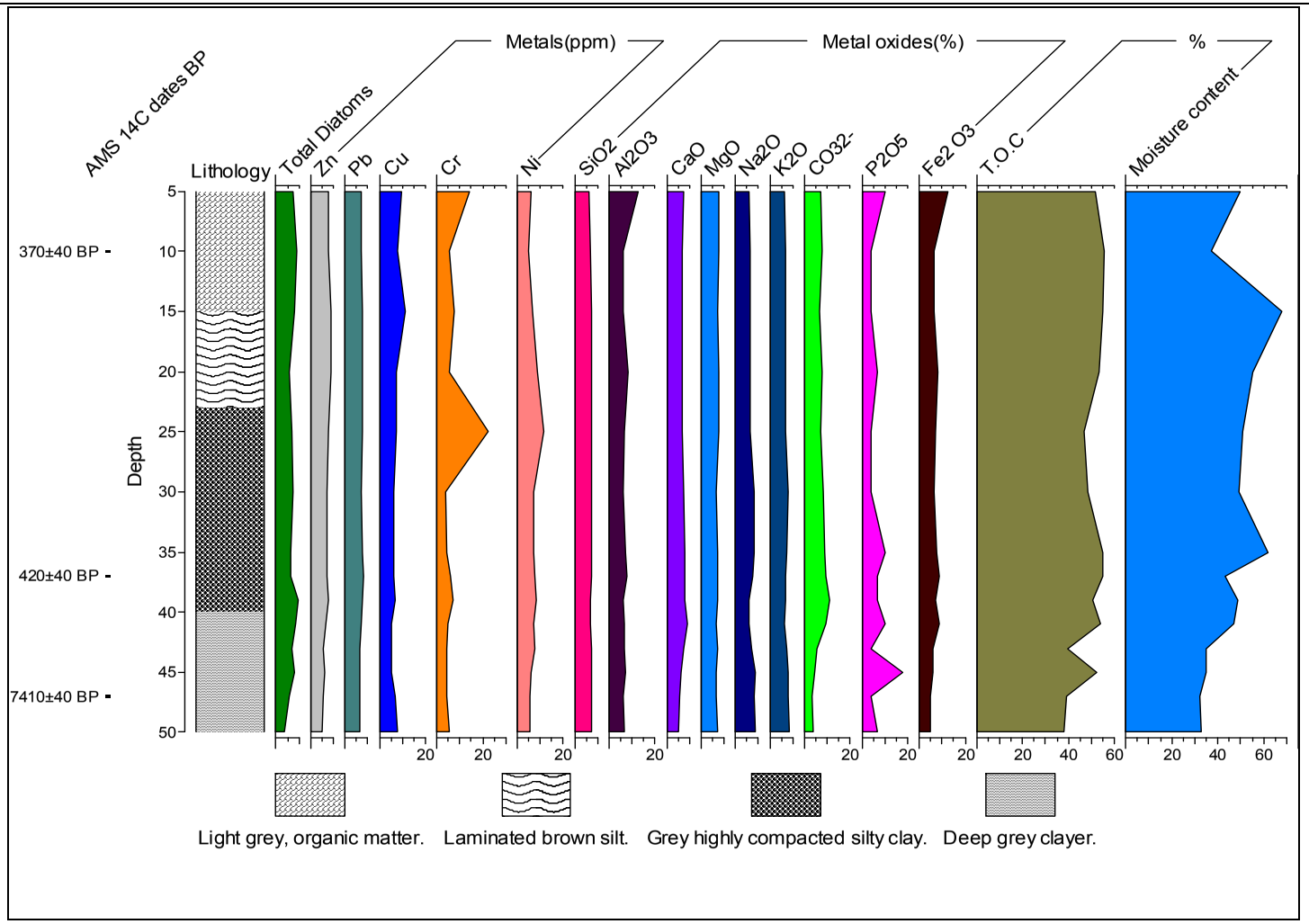

Figure 5.3 Geochemistry of Ondiri Swamp showing different chemical content at various levels

5.4 Analysis of metal and trace metals concentrations

5.4.1 Zinc

The metal has not been studied extensively to have an effect on diatom communities but may affect lactate metabolism with Zinc as a major constituent (Werner, 1977). The downward concentration decreased steadily with depth the highest concentration attained at level 10-15cm (3.1ppm, ~10%)) and 15-20cm (3.08ppm, (~10%)) and the lowest concentration at 47-50cm (1.99ppm, (~5%)). A notable point may be that the topmost parts below 10cm there is considerably low Zinc concentration (Figure 5.4).

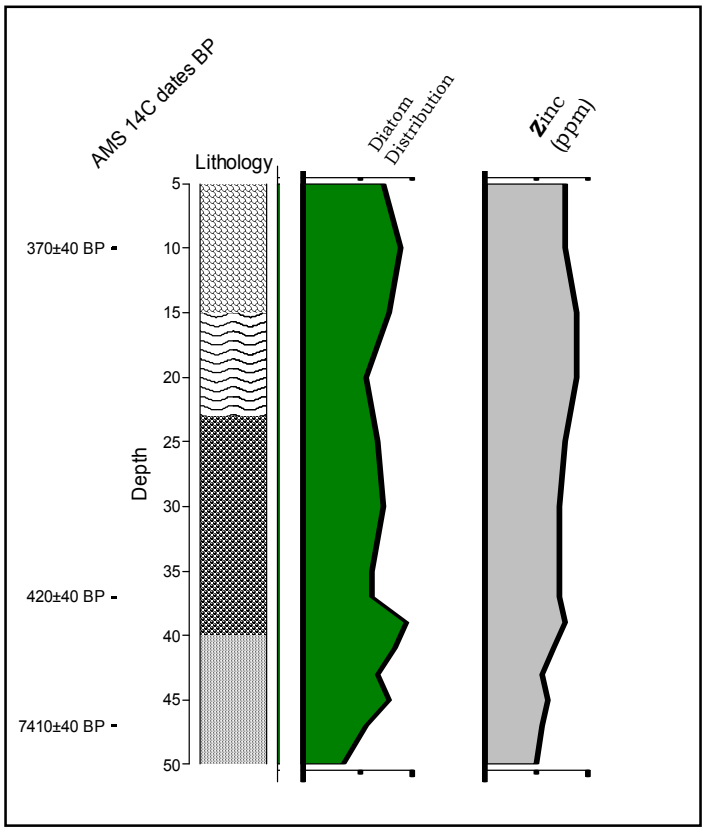

Figure 5.4 Zinc concentrations decreasing with depth

5.4.2 Lead (Pb)

Lead is a heavy metal and occurs as a trace element and is a good indicator of pollution in sediments. The trend decreased almost linearly with depth within the Ondiri Swamp sediment core and varied between 0.7 and 1.0 pmm (Figure 5.5) the highest concentrations attained at level 35-37cm (0.91ppm, ~10%) and the lowest concentrations at 47-50cm (0.7pmm, ~6%).

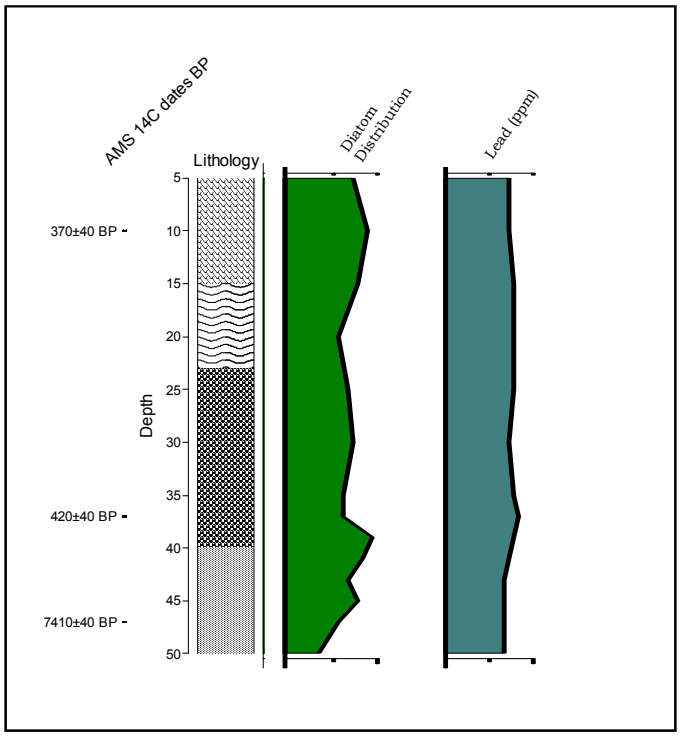

Figure 5.5 Lead concentration variations of Ondiri Swamp core sediments

5.4.3 Copper (Cu)

Copper in very small amounts is necessary for the metabolic processes of many algae. In large concentration it becomes toxic (Werner, 1977).Copper is one of the trace metals and during the Iron Age was a common metal used to make the modified tools. Increase in its concentration may signify change of land use (especially occupation by people) within the area that particular time in history .The Ondiri Swamp core copper concentrations decreases (Figure 5.6) invariably with depth the highest attained at 10-15cm (0.34pmm, ~15%) and the lowest at 39-41cm and 41-43cm (both at 0.15pmm, ~5%).

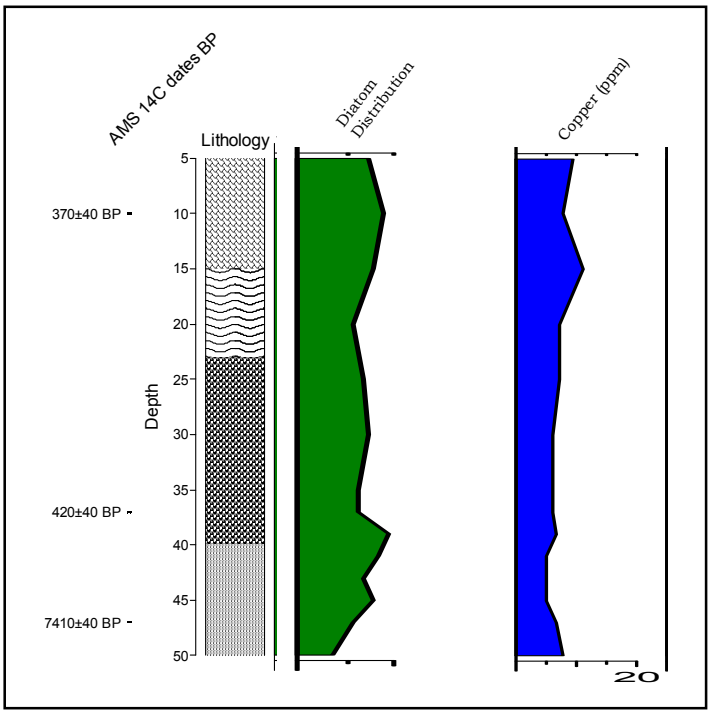

Figure 5.6 Copper concentration variations of Ondiri Swamp core sediments

5.4.4 Chromium (Cr)

This is a trace metal which occurs in sediment and its concentration affects micro-biotic life. The concentration is seen to be highest at level 20-25cm (1.05 ppm, ~25%) and also peaks at the topmost level 0-10cm (0.67ppm, 15%).The lowest level being attained at 25-30cm (0.18 ppm, ~5%) (Figure 5.7)

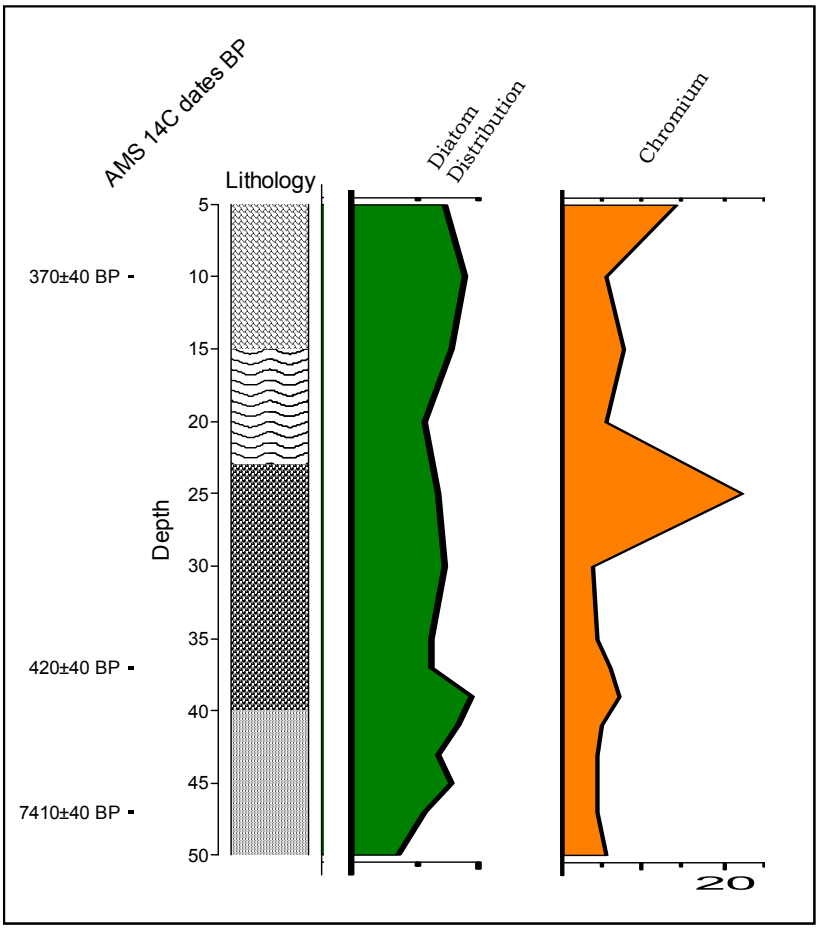

Figure 5.7 Chromium concentration variations of Ondiri Swamp core sediments

5.4.5 Nickel (Ni)

The trace metal nickel is vital for the growth of some species of diatoms. The trend seems to be similar to Chromium trend especially at the depths of 20-25cm. The highest concentration was attained at level 20-25 (0.87ppm, ~15%) and the lowest at 45-47cm and 47-50 (both at 0.43ppm, ~6%), (Figure 5.8)

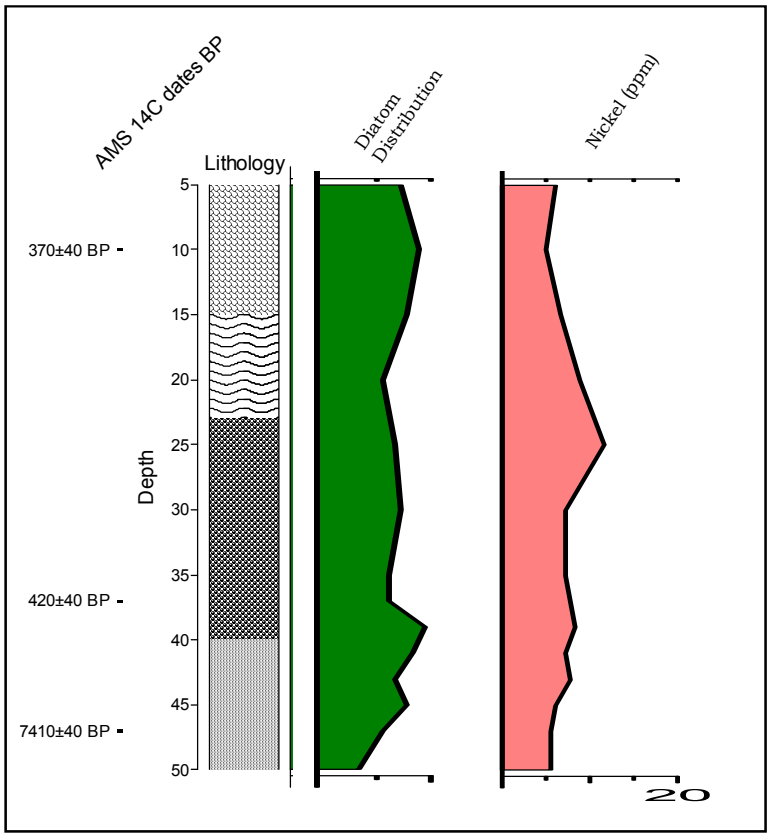

Figure 5.8 Nickel concentration variations of Ondiri Swamp core sediments

5.5 The Oxides variations with depth

5.5.1 Silica Oxide (SiO_2)

Silicon plays a major role in the chemistry of most soils sediment because it is the main constituent of all rock forming minerals. Diatoms frustules are composed of silica and the concentration may affect the generation of this microfossil as it greatly affects the subphydryl groups and in Ondiri lithology the more compacted clay layer had the highest amount of silica yet the diatoms distribution here was poor. Silica oxide values are very high and have shown very little variations within (Figure 5.9) the sediment the highest concentration being at level 47-50cm (60.4%) and the lowest at 39-41cm (52.1%).

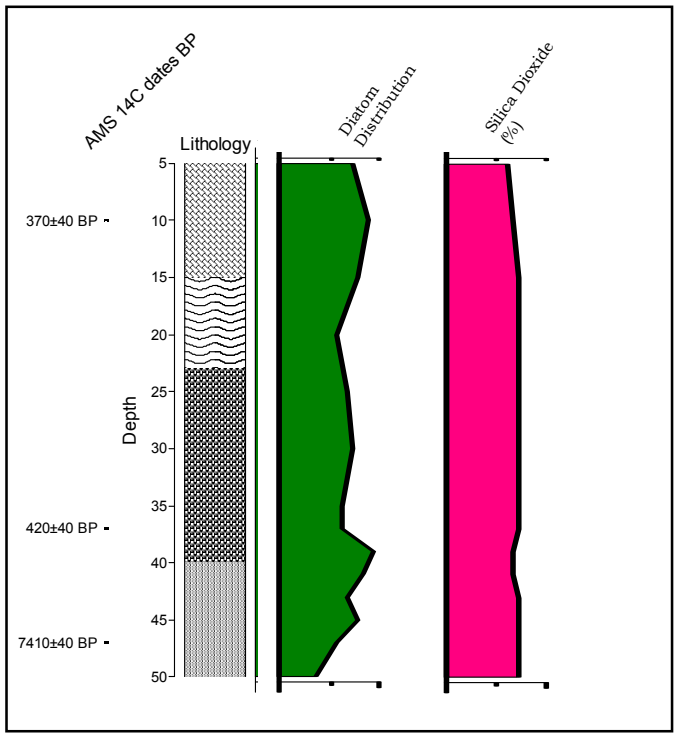

Figure 5.9 Silica Oxide concentrations increasing with depth

5.5.2 Aluminium Oxide (Al_2O_3)

The trend of Oxide of Aluminium oxide decreased with depth (Figure 5.10) the highest values attained at the topmost part of the core with 0-5cm (28%) and lowest at 20-25cm (13.9%). The increase at the topmost level may be due to increase in industrial material of Aluminium content being swept and deposited at the swamp.

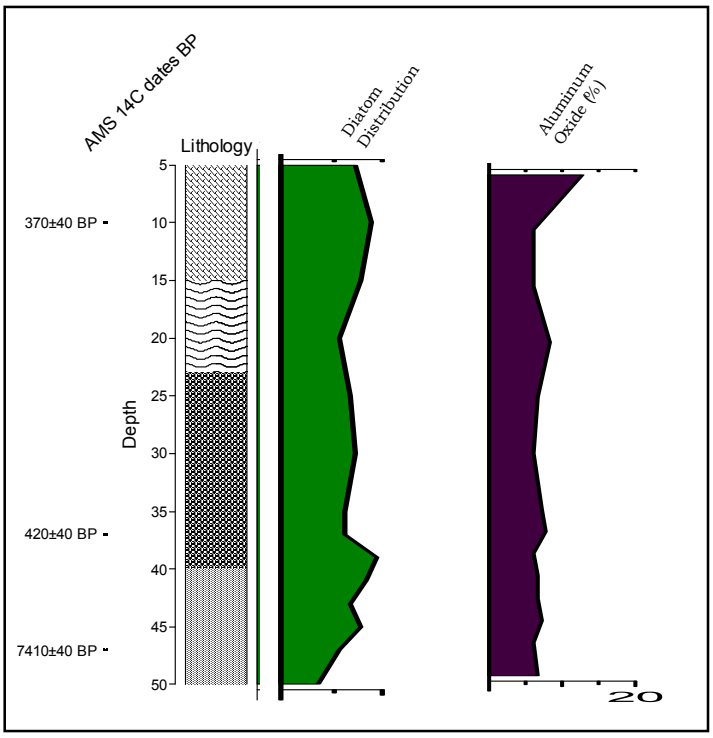

Figure 5.10 Aluminium Oxide concentrations decreasing with depth

5.5.3 Calcium Oxide (CaO)

Calcium is an alkaline ion and is extremely important in the carbonate-bicarbonate buffering systems because it controls the precipitation of many heavy metals and excessive phosphate and is beneficial to diatom growth. Calcium is a major constituent of plant and animal's exoskeleton and the concentration level may inhibit growth of micro-organisms which are the first in the food chain. At Ondiri Swamp the concentration was highest at level 39-41cm (0.77%) and lowest at 47-50cm (0.46%) showing almost a linear down core variability in the trend (Figure 5.11).

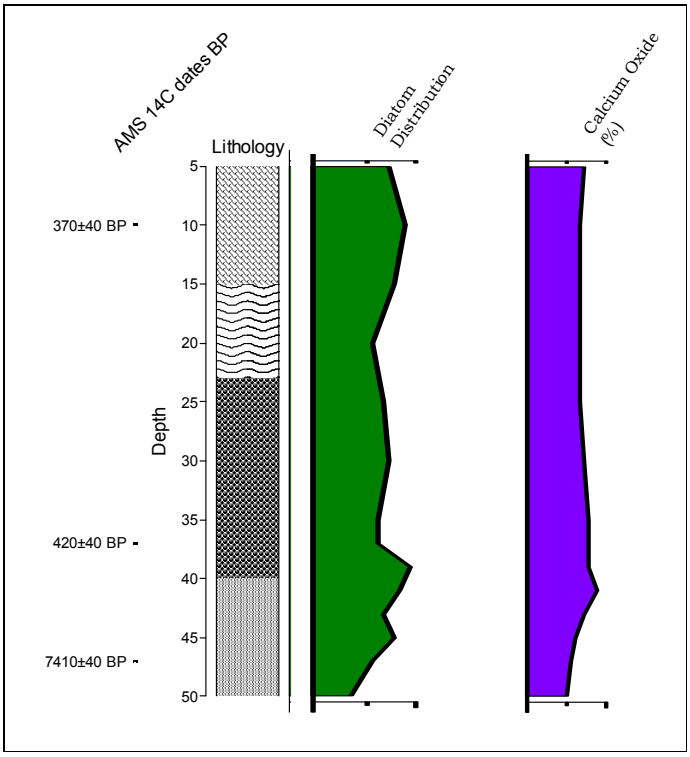

Figure 5.11 Calcium Oxide concentration down-core increase

5.5.4 Magnesium Oxide (Mg O)

Magnesium is one of the alkaline ions commonly found in surface water and is a major contributor to the hardness of water and hence plankton or euplankton or benthic microscopic communities which thrive under these conditions dwell well. The concentrations of the oxide was not very varied with changing lithology and this also never affected the diatoms concentrations and the values were highest was at the topmost part 0-5cm (0.21%) and lowest at 25-30cm (0.17%), (Figure 5.12).

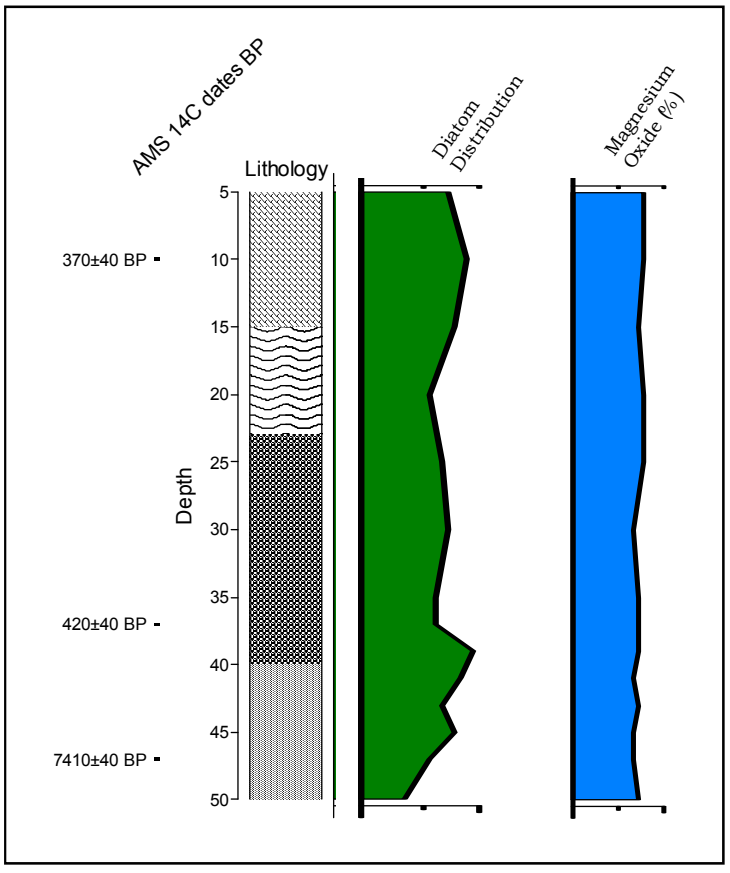

Figure 5.12 Magnesium Oxide concentrations decreasing with depth

5.5.5 Sodium Oxide (Na_2O)

Sodium is a very reactive metal hence it is much more soluble in water contributing to the alkalinity of the water. Sodium chloride is one of the most important salts which limits the distribution of diatoms species its concentration may affect plant or animal growth drastically depriving it of the major element for exoskeleton development. Ondiri core sediment had increased concentrations (Figure 5.13) with a down core increase, the highest at 47-50cm (1.9%) and lowest at 0-5cm (1.24%).

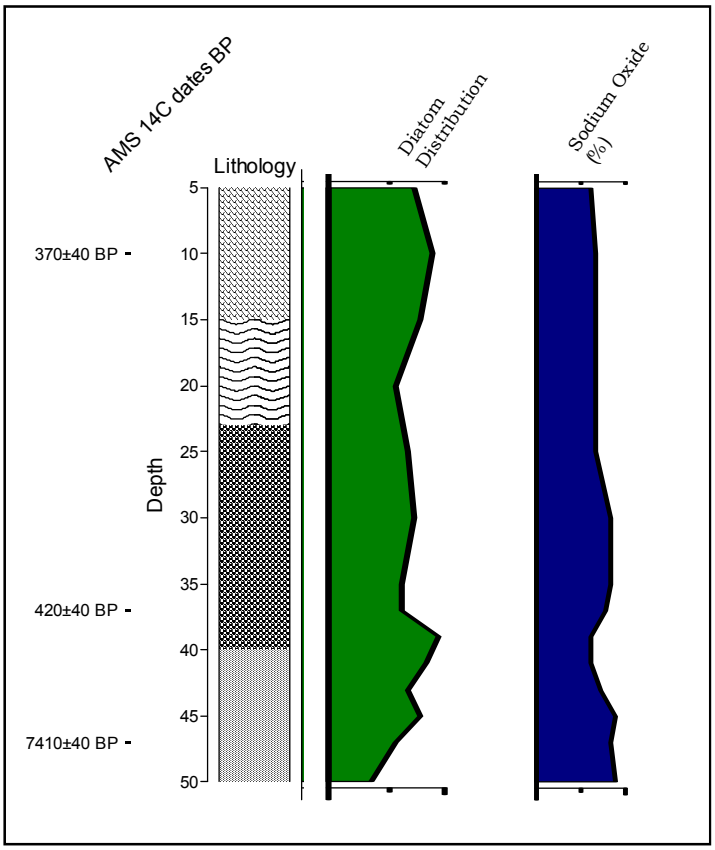

Figure 5.13 Sodium Oxide concentrations increasing with depth

5.5.6 Potassium Oxide (K_2O)

Potassium like Sodium is an alkali metal which causes change in alkalinity of most surface waters. Ondiri Swamp core steadily increased in concentration (Figure 5.14) with depth never showed any major down core variations within its sediments as the highest concentration were at 47-50cm (2.21%) and lowest at 0-5cm (1.65%).

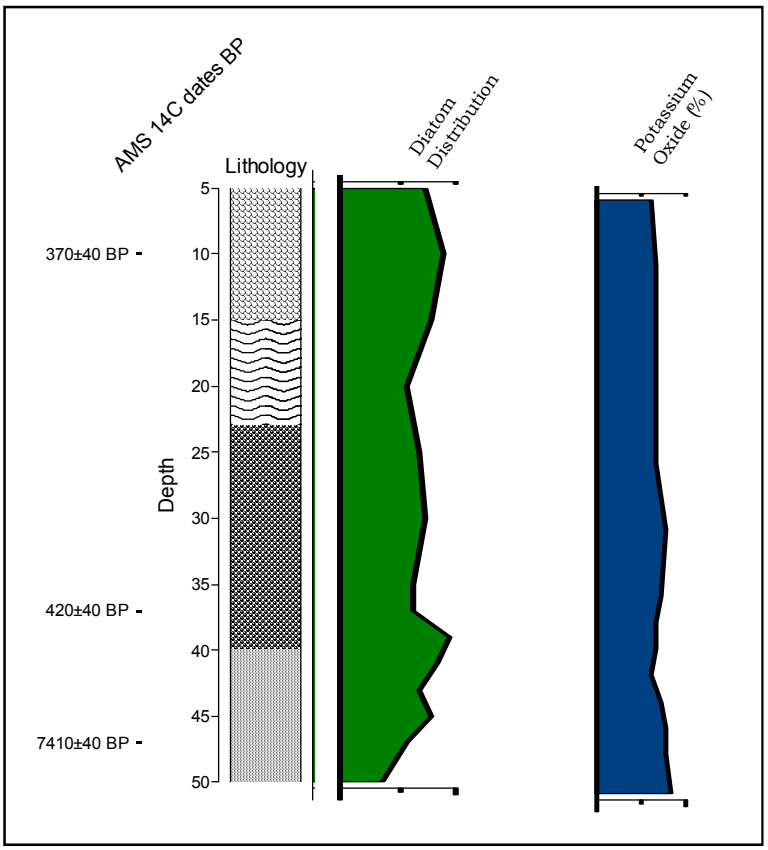

Figure 5.14 Potassium Oxide concentrations increasing with depth

5.5.7 Carbon Dioxide (CO_3^{2-})

In most waters there is sufficient carbon present in the form of CO_2 or carbonated or bicarbonates for diatom growth. The pH of water or sediments determines the most soluble form for microbial use. The carbonate content of the sediment may be compared to the organic matter content, the highly compactly clay layer had the highest concentrations of carbonates at 37-39cm (0.77%) and lowest towards the end of the bottom of the core (0.27%).

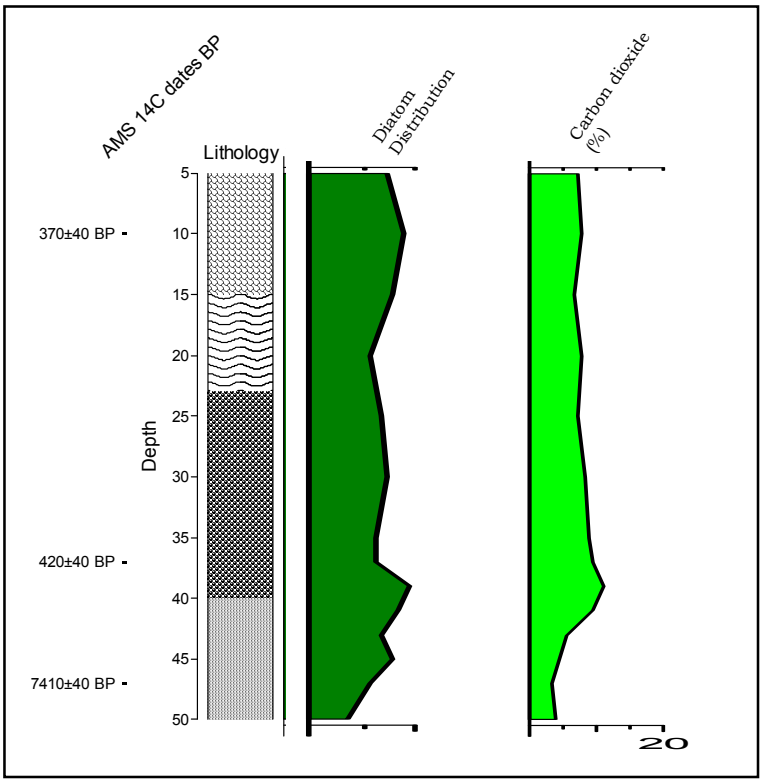

Figure 5.15 Carbon dioxide concentrations decreasing with depth

5.5.8 Phosphorus Oxide (P_2O_5)

The phosphorus is increasing with increasing depth (Figure 5.16), meaning that despite the heavy cultivation (increase in eutrophication) of the area, the level of phosphorus at about 7410 years ago was much high that today. The highest concentration was at level 43-45cm and 0-5cm (0.0018and 0.001%) and the lowest concentrations is at levels 5-15cm, 20-30cm, 40-43 and 45- 47 cm (all at 0.0004%).

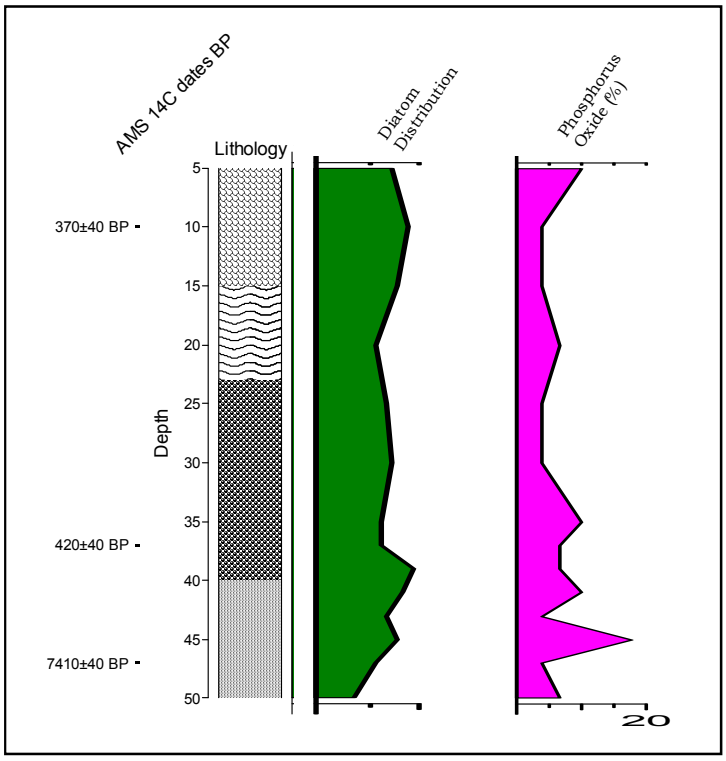

Figure 5.16 Phosphorus Dioxide concentration increasing with depth

5.5.8 Ferric oxide or Iron Oxide (Fe_2O_5)

Most of the sediment which have been leached or laterized contain Iron that is why top-most clayer soils have a lot of Iron content especially during the wet season when the water gets drained into the swamp. The increase in Iron content may be as a result of redox reactions or input of weathered materials to the swamp, but if there is a big gap in the geological record as in the case for Ondiri Swamp depicted by the variations in the rated of depositions and the sediment accumulation rates (from Table 5.1).The general trend (Figure 5.17) of the ferrous material in the sediment at Ondiri Swamp was highest at levels 0-5cm (12.3%) and lowest at 47-50cm (4.69%)

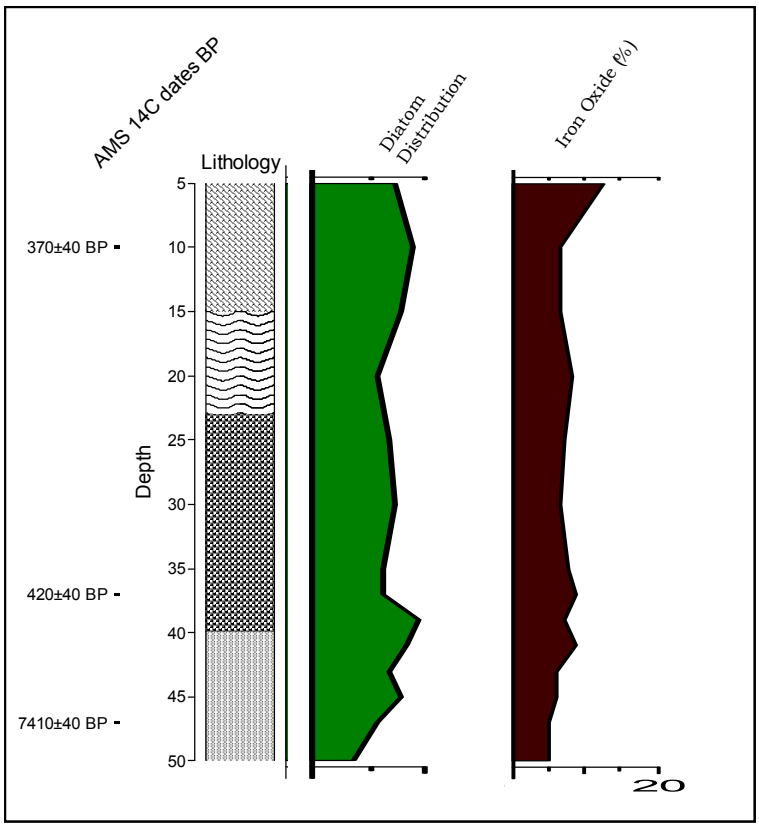

Figure 5.17 Iron Oxide concentrations decreasing with depth

CHAPTER SIX

INTERPRETATION OF ONDIRI SWAMP STRATIGRAPHY

The diatom communities at Ondiri swamp reveal a great deal about the history of the swamp. There are three dominant communities (Figure 6.1) namely *Strauroneis phoenicenteron, Pinularia tropica* and *Amphipleura pellucida* which appear throughout the time zones but their distribution is very varied throughout the stratigraphic column. Other species which were dominant at ages 1 (7450 to 7370 yr BP) and 2 (460 to 380 yr BP) were *Eunotia pectinalis*, *Eunotia tenella* (Figure 6.1). Ages 2 (460 to 380 yr BP) and 3 (410 to 330) was mainly dominated by were *Navicula tenella.* The latter two age levels seem close in age range and appear to be dominated by almost similar group of diatom communities. The interpretation of the core was done using the three age ranges of the core and analyzed with the chemistry at that particular age range.

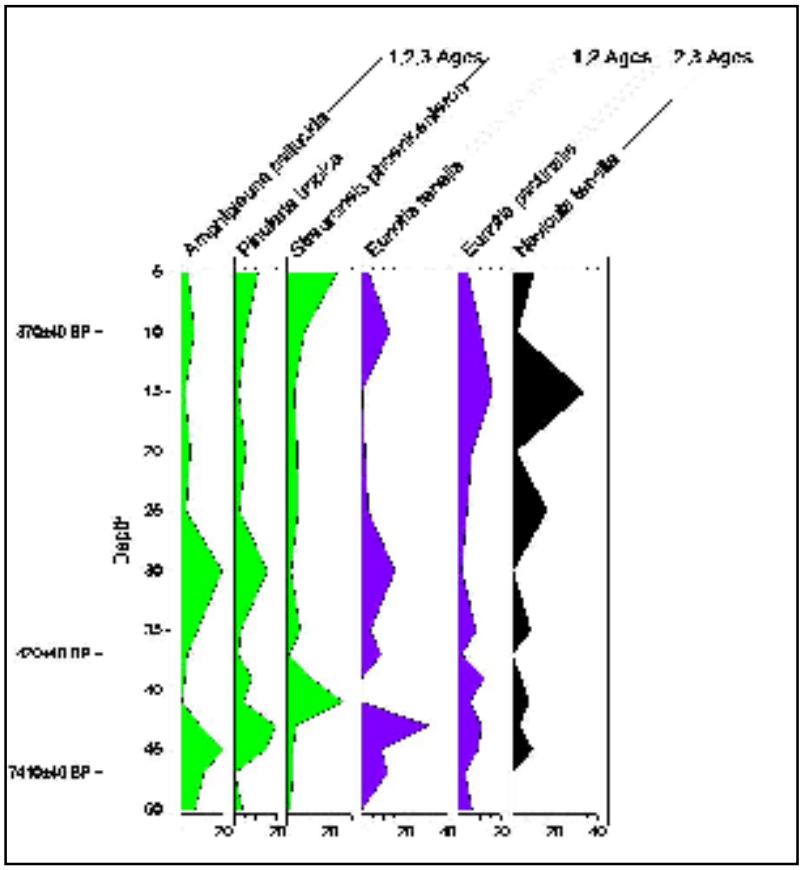

Figure 6.1 Diatoms species common at different time zones

(1- (from 7450 to 7370 yr BP), 2-(from 460 to 380 yr BP) and 3- (from 410 to 330 yr BP)

7450 to 7370 yr BP: Zone Ondiri 1

Diatom communities dominating the lower part of the core were *Amphipleura pellucida, Navicula gawaniensis* and *Pinularia tropica* others were *Eunotia tenella*, *Melosira ambigua*, *Nitzschia subrostrata, Surirella sp.* and minor assemblages of *Eunotia pectinalis*, *Cyctotella iris*, *Nitzschia latens* and *Strauroneis phoenicenteron*

Similarity age range data from Lake Naivasha, the dominant species at this particular age were *Cyctotella sp, Nitzschia subrostrata* and *Nitzschia latens* in Lake Victoria, similar diatoms dominating at this age was *Melosira ambigua* (Richardson et al., 1972) and in Lake Turkana *Melosira spp.* and *Stephanodiscus sp*. which were minor in Ondiri Core dominated at this particular age. The highest water level during this period is represented by the times when *Melosira ambigua* was one of the dominant species over other diatoms communities.

From the interpretation given by authors from both regions, the lake level at this age range indicated by the existence of these similar species, fairly stable and large and later shrunk to dryness after about 5,000 yr. BP and again rejuvenated after 3,000 yr BP to a small size with fluctuating conditions.

From the geochemical analysis of the swamp, all the metal and trace elements reduced in concentrations down core and all other oxides of metals or non metals except for Silicon, Sodium, Potassium and phosphorus. The conditions of water at this particular time was more alkaline indicated by the increase in the alkali metal oxides while the hardness of the water was relatively less down core indicated by reduction of the oxides of the earth alkaline metals reducing in trend.

Similar times in history, data from Lake Naivasha (Richardson, 1966), Lake Turkana (Owen et al., 1982) and Lake Victoria (Kendall, 1969) where analyses were done using the exchangeable cations of Calcium, Magnesium, Sodium,

Lithium, Strontium and Potassium indicate almost similar findings but with varying degrees in concentrations.

460 to 380 yr BP: Zone Ondiri 2 and Ondiri 3

Other dominant species like *Amphipleura pellucida* and *Strauroneis phoenicenteron* from the last age range reappear but reduced in abundance. New smaller species of diatoms including; *Gomphonema gracile, Navicula tenella* and *Navucula el Kab* and others *Navicula halophila,* and *Nitzschia linearis* start to appear. Minor but very important indicator species of more alkaline conditions also start to appear e.g. *Eunotia pectinalis*, *Eunotia tenella*, *Frustulia rhomboides, Gomphonema parvulum*, *Navicula hassiaca*, *Navicula minusculoides*, *Navicula salinicola*, *Nitzschia intermedia*, *Nitzschia palea, Hantzschia amphioxys* and *Pinularia appendicula*.

Analyses from Lake Naivasha indicate similarity in species dominance like *Nitzschia palea*, *Nitzschia intermedia, Nitzschia linearis* and *Navucula el Kab* at almost similar age range. The dominance of *Nitzschia spp.,* species is good indicators of alkaline waters (Appendix six) and also indicates times of lower water hence the 20th century has seen lowest water levels as experience in Ondiri Swamp. Richardson et al., (1972) compared the ionic levels in Lake Naivasha core at this particular time with Lake Rukwa and reported that the salt content was more than twice that of Lake Naivasha but exhibits similar species dominance.

The chemistry of this time was characterized by increase of metals like Chromium, Nickel, Copper and Zinc in lager amount as compared to other age ranges. The oxides of Potassium, Sodium, Calcium and Magnesium were slightly higher than the previous years. This age in archaeology is characterized by the beginning of use of metallic material especially during the Iron Age for cultivation of land (Lane, 2005) and major increase in population levels and activities related to production of food and iron. Ondiri Swamp may have experience a restructure or change in land-use from the domain to more extensive agricultural activities.

410 to 330 yr BP to present: Zone Ondiri 4

The dominant species in this age range are *Strauroneis phoenicenteron* and *Pinularia tropica* which suddenly sprout again from the last age (7410 ±40). *Navicula tenella*, continued its dominance from the second age range (420 ± 40) and *Rhopalodia gibberula* makes its first appearance as a minor specie.

Owen et al., (1982), suggested that lower levels indicate a dramatic decline in planktonic species like the *Melosira sp* and an increase in shallow water forms like *Rhopalodia sp. and* abundant planktonic diatoms combined with scarcity of benthic and epiphytic species suggests a period of deep water and higher lake levels.

The geo-chemistry of Ondiri Swamp reveals a great deal on the change of land use at this particular age range. The levels of Aluminum oxide, Magnesium oxide, Phosphorus oxide and Iron oxides are highest indicating very heavy cultivation of land and use of induced agro-ecological fertilizers and the expulsion of heavy chemicals to the swamp by inhabitants through industrial development and fertilizers have very high values of phosphates and nitrates (Kinyanjui, 2003). Most of these chemical were easily washed away to the swamp after use as phosphorus easily attaches itself to soils and gets transported downstream. The organic matter content and moisture content at these ages is relatively low and may be explained by the pollution effects in the swamp.

Kinyanjui, (2003) recovered a core at the shallower end (periphery) of the swamp and the age range may fall at this particular time zone, reported a great decrease in terrestrial and aquatic pollen dominated by grass (Poaceae) shrubs (*Astreraceae, Amaranthaceae/ Chenopodieceae*) with a sharp increase in sand portion (Silica) and made inference that this period has experienced heavy agricultural activities.

CHAPTER SEVEN

DISCUSSIONS

The major theme of the current research was to establish the Paleoclimate of Ondiri Swamp and its catchment and make inferences of the greater region. The combined sedimentary data from Ondiri Swamp provides a good record of the diatoms, vegetation (Kinyanjui, 2003) which when linked to the geochemistry of the past waters and sediment conditions that existed in history reveal climatic variability. The data appears roughly in phase with other records from Kenya and Eastern Africa with some puzzling differences that may hint at the local tectonic influences on the sedimentary record (Figure 3.2) with varied dry and wet periods observed in the lithology.

The date at the bottom of the core (7410±40 yr BP) may have been incorrect as the regression curve reveals through contamination or in co-operation of reworked organic matter. There is also observed effect on diatoms distribution and silica levels have decreased at this particular depth (47cm-50cm). The age-depth curve suggests a low rate of sediments accumulation during this period or perhaps more likely the occurrence of one or several hiatuses in sedimentation. There are several dry levels which reveal low or no substantial amount of water in the swamp and increased sediment inputs. Although fragmentary and not highly resolved, the available data suggests the paleo-environmental conditions at Ondiri before 4,000 yr BP were a response to higher levels of effective precipitations and lower levels of human activity than today.

The modern analogues of Ondiri Swamp diatoms are not perfect analogues however suggestive and the observed species found on the upper part of the core are largely planktonic and are found in small wetlands in East Africa today.

The carbon isotopic ratios (^{13}C /^{12}C) from the lower (bottom 45cm -37cm) depths reveal tropical aquatic soils/sediments with more of C_3 plants and less

productivity in the swamp and this may not have been the best level to use for dating. The upper level (topmost part of core) values are typical of disturbed environment with terrestrial inputs of dominant C_4 material or switch from C_3 to C_4 dominating microphytes (Olago et al., 2000b).

Inferences about the past chemical conditions are partly interdependent and are best discussed together with the lithology and diatoms communities within these levels. The observed total ion content e.g. dissolved silica at the lower part of the core does not have a great difference compared to the upper part.

My suggestion that the swamp was smaller on the later ages (after 370±40 yr BP) is based on larger numbers of genus *Nitschia* and *Navicula* and their abundance may signify water rather than nutrients including organic nutrients which were abundant at the topmost level of the core.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Ondiri Swamp and the surrounding areas have witnessed several changes in the climatic patterns from the past deduced from the evidence of existing fossil diatoms, vegetational changes and the sediment geo-chemistry.

The first phase saw the swamp having relatively high water levels, several non depositional/erosional/dry phases (the non-conformity after the dated 7410±40 yr BP) and later a closed up in response to change of swamp usage due to encroachment and anthropogenic activities in the recent times.

Sources of controls of the paleoclimate were probably geologically or tectonically controlled given the down core variation in the lithology, changes geo-chemistry of the sediments and the affinities of the diatoms communities at the Swamp.

Recommendations for policy makers and further research

Ondiri Swamp is located at a very convenient zone for many researchers who investigate paleoclimatic changes yet very little interest is geared towards investigating the climatic conditions of the area. Most work is concentrated in far regions like Lake Turkana, Lake Magadi regions, Suguta area, Lake Challa or Lake Victoria and the climatic patterns are similar to the conditions experienced at the Swamp although from a very small perspective.

In Africa long term environmental change patterns and land-use is not known but the tropics plays a very vital role in climatic controls through the monsoonal variations in climatic patterns. This information is vital for policy makers to implement effective land use management to protect the catchments and the aquatic /micro-biotic life.

Paleoclimate has several factors which need to be investigated to come up with a very comprehensive view as combined data analysis and follow-ups need to be

made to make paint a good picture on what conditions prevailed during the last few centuries.

A good recommendation to add on to the studies of diatoms should be to investigate the silica competitive phytoliths communities which were observed during microscopic analysis. Charcoal, spores and pollen are also very good indicators to past environment so to conclusively determine the past environment, these should be investigating given the age of the swamp has been determined.

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Appendix One: Species at Ondiri Swamp (Raw Data)

Species names	0-5cm	5-10cm	10-15cm	15-20cm	20-25cm	25-30cm	30-35cm	35-37cm	37-39cm	39-41cm	41-43cm	43-45cm	45-47cm	47-50cm
Achnathes exilis									2					4
Amphora coffaeformis									2			3	1	
Amphora geneta			3											
Amphora kenyensis			2											
Amphora montana					1									
Amphora ovalis	3													
Amphora pediculus									1					
Amphora strigosa					2					1				
Amphora subacutiuscula	4					1								
Amphora tenarescens				1	1							3	4	
Amphora veneta	11	1		6	3		4	2	2		2			
Anomoenoneis sphaerophora				2										
Amphipleuria pellucida	15	28	9	19	12	81	33	13	10	3	39	83	45	30
Brachysira vitrea										1				
Cryptotenella													15	
Cyctotella iris														
Cymbella affinis	1													
Cymbella amphicephala								3						
Cymbella beccani		1												
Cymbella fonticola										2				
Cymbella perpusilla				1		1								
Cymbella sp.			8	4	7									
Cymbella turgida		4					12							
Eunotia curvata				3				1		2			4	
Eunotia flexuosa	17	5	3	1		1								
Eunotia montana												7	1	
Eunotia naegelli										3			1	
Eunotia pectinalis	9	22	33	13	8	3	17	3	25	11	22	19	6	13
Eunotia praerupta														
Eunotia tenella	5	20		2	4	24	6	14			49	14	19	
Eunotia veneris		7		1										
Eunotia vumbae					2			1					4	
Flagillaria orotonensis			1							1	2			
Frustulia rhomboides		7	19	5	3	3	16	1	20	33	6	7	3	
Frustulia vulgaris										15				
Gomphonema gracile	4	7	10	1	33	2	3	60	12	7		7	11	
Gomphonema parvulum			8			1		18				2	6	7
Hantzschia amphioxys	10	13	21		6		13	1	16		7	7	9	5
Luticola						12								
Melosira ambigua										2		3	32	
Melosira americana													2	3
Melosira distans		1			7						1			
Melosira varians						3	2							
Navicula accomoda							3			1				
Navicula bryphila						6								

Species names	0-5cm	5-10cm	10-15cm	15-20cm	20-25cm	25-30cm	30-35cm	35-37cm	37-39cm	39-41cm	41-43cm	43-45cm	45-47cm	47-50cm
Navicula contenta			3											
Navicula cuspidata					2					5				
Navicula disjuncta	1								4	1				
Melosira granulata												13	7	3
Navicula elegantula									2					
Navicula elkab		55		61	1							11		4
Navicula fenerbornii			6			2		7				2		
Navicula gawaniensis			18	6	3	8	4	17	23	16		5	3	34
Navicula halophila		13		36	16			16	58	5			2	
Navicula heuflevi			3											
Navicula palea														
Navicula hassiaca			20		35		19	16	3		6			
Navicula plateneis										7				
Navicula radiosa				4				1						
Navicula sigmoidea						24								
Navicula sp.					2	28				18		4	3	5
Navicula salinicola	1	34		7	12		5		3					
Navicula tenella	28	7	92	6	45	2	24		12	21	10	26		
Navicula subtilisima	2	11	6		2		6	12	12	5	3	5	1	2
Navicula symmetrica		3						2		8		2		
Navicula trivialis	4											2		
Nitzschia aequalis		1		2				2						
Nitzschia alexandria		1												
Nitzschia amphibia										1				
Nitzschia communis		2		4	1	7								
Nitzschia dissipata														
Nitzschia elegentula			12		11									
Nitzschia estohensis					1									
Nitzschia fonticola	2			5									2	
Nitzschia gracilis									1	6				
Nitzschia hungarica										2				
Nitzschia intermedia		6					19		18	19		5	8	3
Nitzschia latens						4				3		23		
Nitzschia linearis	10	58	44	22	21	29	21	36	45	8	8	2	4	2
Nitzschia nyassensis		9						2						
Nitzschia obtusa W. Sm	2			1	2									
Nitzschia palea					11	14	13	21	10			9	21	
Nitzschia sigma										8	4			
Nitzschia spectabilis					2									
Nitzschia subrostrata		1	6	4	15			9	5					19
Pinularia subcapitata Greg.			13		12		3		10			3		
Pinularia tropica	39	18	8	19	9	53	10	8	29	15	66	52		14
Pinularia viridis var. *commutata*		19								6				
Pleurosigma salinanum	3	1	7	2	2	6	4	1	2		1			
Rhoicospherua curvata					1									
Rhopalodia gibba								2	5					
Rhopalodia gibberula	23					9		1			3	5	10	
Rhopalodia gracilis		1				1						6		

Rhopalodia vermicularis				1						3				
Species names	**0-5cm**	**5-10cm**	**10-15cm**	**15-20cm**	**20-25cm**	**25-30cm**	**30-35cm**	**35-37cm**	**37-39cm**	**39-41cm**	**41-43cm**	**43-45cm**	**45-47cm**	**47-50cm**
Stephanodiscus astreaea	2			2		1						1		
Strauroneis acuta	25					4		5	22	7			5	
Stauroneis crucicula										15				
Strauroneis enceps						2								
Nitzschia thermalis				1							3	6		
Nitzschia tropica		3											18	
Nitzschia vitrea							4	3						
Pinularia americeona										1				
Pinularia appendicula	2			8			16							
Pinularia biceps					2									
Pinularia borealis							2				2			
Pinularia gibba		5							11					
Pinularia microstauron	2									2		10		
Strauroneis phoenicenteron	119	41	15	23	27	9	30	4	58	134	22	13	14	5
Surirella gibberulla				3										
Surirella linearis												6		
Surirella orata										1		7	12	
Surirella sp.	4		1	1	1	6	1		3		32	2		1
Synedra acus						2					25			
Synedra barolinenesis			4				1		6					
Synedra dersirentralis													5	
Synedra hartii					2									

Appendix Two: Alkalinity preference of observed diatoms at Ondiri Swamp

Species names	Alkalinity (meq.1^{-1})
Melosira ambigua	2
Amphipleuria pellucida	2
Eunotia pectinalis	2
Nitzschia intermedia	2
Nitzschia nyassensis	2
Frustulia vulgaris	2
Nitzschia tropica	2
Pleurosigma salinanum	2.3
Navicula sp.1 af. minusculoides	6.7
Navicula symmetrica	45
Navicula halophila	100
Frustulia rhomboides	100
Navicula plateneis	100
Nitzschia elegentula	100
Surirella sp.1	100
Nitzschia palea	10-100
Synedra acus	10-100
Pinularia appendicula	14.6-63.4
Nitzschia linearis	2-10.0
Melosira granulata	2-10.0
Navicula sp. 2 af. salinicola	2-10.0
Cymbella tumida	2-10.0
Navicula fenerbornü	2-10.0
Navicula subtilisima	2-10.0
Eunotia flexuosa	2-10.0
Nitzschia communis	2-10.0
Eunotia tenella	2-10.0
Gomphonema gracile	2-100.0
Achnathes exilis	2-100.0
Eunotia montana	2-100.0
Pinularia tropica	2-50.0
Surirella ovata	2-50.0
Rhopalodia gibberula	2-50.0
Strauroneis acuta	2-50.0
Navicula hassiaca	2-50.0
Melosira distans	50-100
Pinularia microstauron	2-50.0
Eunotia veneris	50-100

Species names	Major alkalinity preference
Pinularia tropica	Acidiphilous
Amphora veneta	Acidophilous
Eunotia flexuosa	Acidophilous
Navicula bryphila	Acidophilous
Navicula fenerbornü	Acidophilous
Nitzschia subrostrata	Aerophilous
Pinularia subcapitata	Aerophilous
Navicula subtilisima	Aerophilous
Navicula plateneis	Aerophilous
Pleurosigma salinanum	Aerophilous
Pinularia viridis* var. *commutata	Aerophilous
Eunotia pectinalis	Aerophilous
Strauroneis phoenicenteron	Aerophilous
Eunotia montana	Aerophilous
Eunotia tenella	Aerophilous
Nitzschia communis	Aerophilous
Navicula elkab	Alkaliphilous
Cyclotella iris	Alkaliphilous
Nitzschia linearis	Alkaliphilous
Frustulia vulgaris	Alkaliphilous
Strauroneis acuta	Alkaliphilous
Synedra acus	Alkaliphilous
Eunotia veneris	Alkaliphilous
Pinularia gibba	Alkaliphilous
Cymbella tumida	Alkaliphilous
***Surirella sp.*1**	Alkaliphilous?
Melosira granulata	Crenophilous-Halophilous and alkaliphiphilous
Nitzschia tropica	Limnophilous
Hantzschia amphioxys	Neutrophilous
Cymbella turgidula	rheophilous

Appendix Three: pH preference of observed diatoms at Ondiri Swamp

Species names	pH
Amphipleuria pellucida	6
Hantzschia amphioxys	6
Navicula hassiaca	6
Navicula subtilisima	6
Gomphonema sp.	6
Pinularia tropica	6
Eunotia montana	6
Eunotia flexuosa	6.5
Nitzschia communis	6.6
Melosira distans	6.8
Nitzschia latens	7
Nitzschia palea	7
Melosira ambigua	7.3
Cyclotella iris	6.0-7.0
Eunotia pectinalis	6.0-7.0
Pinularia gibba	6.0-7.0
Frustulia rhomboides	6.0-7.0
Synedra acus	6.0-7.0
Nitzschia nyassensis	6.0-7.0
Amphora veneta	6.5-6.8
Navicula elkab	6-7(Optimum 7.8-8.2)
Navicula bryphila	6-8.5
Nitzschia linearis	6-8.5
Melosira granulata	6-8.5
Navicula plateneis	6-8.5
Navicula symmetrica	6-8.5
Frustulia vulgaris	6-8.5
Surirella ovata	6-8.5
Pleurosigma salinanum	6-9.5
Eunotia veneris	6-9.5
Nitzschia subrostrata	6-9.5
Pinularia viridis* var. *commutata	7 Optimum 7.5-8.0
Pinularia appendicula	7.5-8 Optimum
Cymbella turgidula	7-8.5
Cymbella tumida	7-8.5
Nitzschia tropica	7-9.5
Navicula gawaniensis	8.5-9.5
***Surirella sp.*1**	8.5-9.5
Gomphonema gracile	8.5-9.5

Species names	**pH**
Achnathes exilis	8.5-9.5
Navicula fenerbornü	9.1-9.6
Nitzschia elegentula	7-8.5
Navicula sp.1 af. minusculoides	8.5-9.5
Rhopalodia gibberula	8.5-9.5
Strauroneis acuta	9.3-9.7
Nitzschia sigma	9-9.5
Navicula sp. 2 af. salinicola	9-9.5
Nitzschia intermedia	9-9.5
Navicula halophila	9-9.5

Appendix Four: Conductivity preference of observed diatoms at Ondiri Swamp

Species names	Conductivity(μS cm^{-1})
Cymbella turgidula	60
Navicula plateneis	212
Achnathes exilis	300
Cymbella tumida	300
Eunotia flexuosa	300
Frustulia rhomboides	300
Hantzschia amphioxys	300
Navicula bryphila	300
Navicula hassiaca	300
Navicula subtilisima	300
Nitzschia linearis	300
Pinularia appendicula	300
Pinularia microstauron	300
Pinularia subcapitata	300
Navicula sp. 3 af. tenella	9,200
Navicula elkab	10,000
Navicula gawaniensis	10,000
Navicula sp. 2 af. salinicola	23,000
Nitzschia elegentula	1,000-10,000
Navicula sp.1 af. minusculoides	1,000-10,000
Rhopalodia gibberula	1,000-10,000
Cyclotella iris	1,000-10,000
Nitzschia communis	1,900-5,000
Surirella sp.1	2,860-3,300
Nitzschia latens	3,000-10,000
Nitzschia sigma	3,000-10,000
Pinularia tropica	300-1,000
Synedra acus	300-1,000
Eunotia pectinalis	300-1,000
Melosira granulata	300-1,000
Navicula fenerbornü	300-1,000
Nitzschia palea	300-1,000
Frustulia vulgaris	300-10,000
Navicula halophila	300-10,000
Pleurosigma salinanum	300-10,000
Strauroneis phoenicenteron	300-3,000

Species names	**Conductivity(μS cm^{-1})**
Nitzschia tropica	300-10,000
Navicula symmetrica	300-3,000
Nitzschia intermedia	300-3,000
Pinularia gibba	300-3,000
Amphora veneta	300-3,000
Nitzschia subrostrata	300-3,000
Melosira ambigua	300-3,000 (Some 70-400)
Nitzschia nyassensis	520-610

Appendix Five: Ecology of observed diatoms at Ondiri Swamp

Species names	Conductivity($\mu S\ cm^{-1}$)
Cymbella turgidula	60
Navicula plateneis	212
Achnathes exilis	300
Cymbella tumida	300
Eunotia flexuosa	300
Frustulia rhomboides	300
Hantzschia amphioxys	300
Navicula bryphila	300
Navicula hassiaca	300
Navicula subtilisima	300
Nitzschia linearis	300
Pinularia appendicula	300
Pinularia microstauron	300
Pinularia subcapitata	300
Navicula sp. 3 af. tenella	9,200
Navicula elkab	10,000
Navicula gawaniensis	10,000
Navicula sp. 2 af. salinicola	23,000
Nitzschia elegentula	1,000-10,000
Navicula sp.1 af. minusculoides	1,000-10,000
Rhopalodia gibberula	1,000-10,000
Cyclotella iris	1,000-10,000
Nitzschia communis	1,900-5,000
Surirella sp.1	2,860-3,300
Nitzschia latens	3,000-10,000
Nitzschia sigma	3,000-10,000
Pinularia tropica	300-1,000
Synedra acus	300-1,000
Eunotia pectinalis	300-1,000
Melosira granulata	300-1,000
Navicula fenerbornü	300-1,000
Nitzschia palea	300-1,000
Frustulia vulgaris	300-10,000
Navicula halophila	300-10,000
Strauroneis phoenicenteron	300-3,000
Navicula symmetrica	300-3,000
Nitzschia intermedia	300-3,000

Species names	**Conductivity(μS cm^{-1})**
Nitzschia tropica	300-10,000
Pleurosigma salinanum	300-10,000
Pinularia gibba	300-3,000
Amphora veneta	300-3,000
Nitzschia subrostrata	300-3,000
Melosira ambigua	300-3,000 (Some 70-400)
Nitzschia nyassensis	520-610

Appendix Six: Major Indicator Diatoms at Ondiri Swamp

Species names	Indicator species
Cyclotella iris	Good indicator of acid waters pH optimun of 5.5-5.8
Nitzschia latens	Low-medium to low alkalinity (0, 5-7 meq. l-1)
Nitzschia tropica	Ocurrance on saline water indicate tolerance to brackish waters
Nitzschia intermedia	Relatively dilute conditions
Rhopalodia gibberula	Strong alkaline waters in E.A
Nitzschia subrostrata	Strong alkaline waters in E.A
Nitzschia nyassensis	When associated with Amphora coffaeformis is a good indicator of ratio of HCO_3^-<1

Appendix Seven: Temperature preference of Diatoms at Ondiri Swamp

Species names	Temperature(^{o}C)
Navicula elkab	10
Surirella sp.1	28
Pinularia subcapitata	28
Pinularia appendicula	50
Strauroneis acuta	10-21.0
Eunotia flexuosa	10-21.0
Nitzschia intermedia	10-21.0
Melosira granulata	10-21.0
Nitzschia elegentula	10-21.0
Amphipleuria pellucida	10-21.0
Eunotia montana	10-21.0
Navicula sp. 2 af. salinicola	10-27.0
Navicula subtilisima	10-27.0
Cyclotella iris	10-27.0
Navicula bryphila	10-27.0
Pleurosigma salinanum	10-27.0
Navicula sp.1 af. minusculoides	10-27.0
Nitzschia communis	10-27.0
Achnathes exilis	10-27.0
Melosira distans	10-27.0
Pinularia gibba	10-27.0
Gomphonema sp.	10-27.0
Strauroneis phoenicenteron	10-27.0
Navicula plateneis	10-35.0
Nitzschia subrostrata	10-35.0
Eunotia pectinalis	12.5-18
Melosira ambigua	21-27.0
Navicula hassiaca	21-27.0
Eunotia tenella	21-27.0
Pinularia microstauron	21-27.0
Nitzschia latens	21-27.0
Nitzschia sigma	21-27.0
Navicula halophila	21-35
Frustulia rhomboides	21-35

Species names	**Temperature(^{o}C)**
Amphora veneta	21-35
Cymbella turgidula	21-35
Synedra acus	27-35
Gomphonema gracile	27-35
Navicula gawaniensis	3.5 - 45
Surirella ovata	Stenothermic
Rhopalodia gibberula	27-35

Appendix Eight:

Moisture content and Organic Matter content of Ondiri Swamp Sediments (Raw data)

A) Moisture Content (W.C) determination at 105^0 C for 720 minutes

Sample No.	Level (Centimetres)	Weight of Aluminium Foil	Weight of sample (Grammes)	Total weight of sample +Foil	Weight after combustion	Total Moisture content	% Moisture Content
SN 1	0-5	0.614	1.19	1.804	1.204	**0.600**	**50.42**
SN 2	5-10	0.527	1.53	2.057	1.485	**0.572**	**37.39**
SN 3	10-15	0.607	1.345	1.952	1.037	**0.915**	**68.03**
SN 4	15-20	0.553	1.267	1.82	1.117	**0.703**	**55.49**
SN 5	20-25	0.596	1.063	1.659	1.118	**0.541**	**50.89**
SN 6	25-30	0.637	1.420	2.057	1.358	**0.699**	**49.23**
SN 7	30-35	0.418	1.101	1.519	0.836	**0.683**	**62.03**
SN 8	35-37	0.445	1.019	1.464	1.022	**0.442**	**43.38**
SN 9	37-39	0.562	1.105	1.667	1.129	**0.538**	**48.69**
SN 10	39-41	0.639	1.134	1.773	1.238	**0.535**	**47.18**
SN 11	41-43	0.684	1.424	2.108	1.614	**0.494**	**34.69**
SN 12	43-45	0.877	1.537	2.414	1.873	**0.541**	**35.2**
SN 13	45-47	0.698	1.341	2.039	1.603	**0.436**	**32.51**
SN 14	47-50	0.675	1.246	1.921	1.512	**0.409**	**32.83**

B) Total Organic Content (T.O.C) determination at 550^0 C for 12 hours (720minutes)

Sample No.	Level (Centimeters)	Weight of Crucible (Grammes) before combustion	Weight of sample (Grammes)	Weight after combustion (crucible +sample) (Grammes)	Total organic content (TOC)	% Organic Carbon
TN 14	0-5	29.622	1.764	30.469	0.917	**51.98**
TN 13	5-10	31.025	1.815	31.829	1.011	**55.7**
TN 12	10-15	27.694	1.571	28.399	0.866	**55.12**
TN 11	15-20	28.415	1.566	29.149	0.832	**53.13**
TN 10	20-25	28.568	1.611	29.426	0.753	**46.74**
TN 9	25-30	27.015	1.756	27.918	0.853	**48.58**
TN 8	30-35	27.625	1.571	28.335	0.861	**54.81**
TN 7	35-37	25.579	1.371	26.193	0.757	**55.22**
TN 6	37-39	31.020	1.603	31.811	0.812	**50.66**
TN 5	39-41	27.688	1.530	28.394	0.824	**53.86**
TN 4	41-43	28.408	1.246	29.163	0.491	**39.41**
TN 3	43-45	27.994	1.396	28.658	0.732	**52.44**
TN 2	45-47	27.615	1.448	28.499	0.564	**38.95**
TN 1	47-50	29.622	1.578	30.597	0.603	**38.21**